A Simulation-Based Analysis of PTSD Prevalence among US Military Personnel and Veterans in 2025

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Draft V10c

Abstract:

We developed and simulated a systems model of the population of military personnel and veterans affected by post-traumatic stress disorder (PTSD). Simulation results fit the historical data on PTSD prevalence in 2000-2014, and forecast the trends for the next decade under several scenarios of US involvement in future wars. Using the model, we tested the effects on PTSD prevalence and healthcare costs of four PTSD policies aimed at improving: 1) resiliency, 2) screening, 3) treatment, and 4) a combination of the three. Results showed that in a postwar period, there is no silver bullet for overcoming the problems of PTSD, and screening and treatment policies must be revolutionized to have any noticeable effect. One critical characteristic of this system is the long time that it takes, about 40 years, to vanquish the psychiatric consequences of a war. In a very optimistic scenario, estimated PTSD prevalence among veterans in 2025 will be at least 10%.

Keywords: Post-traumatic stress disorder (PTSD), system dynamics, systems science

1. Introduction

Wars have considerable invisible costs, a major one being mental illness, for military personnel, veterans, and their family members [1]. Post-traumatic stress disorder (PTSD) stands out as a major life-threatening mental illness. It is the result of experiencing trauma, and the illness often shows symptoms long after events. Currently, more than two percent of the US population (about 7.7 million people) are known to suffer from PTSD, and eight to nine percent of the US population report experiencing lifelong PTSD [2]. The cascading effects of PTSD and comorbidity with other illnesses threaten patients' lives. People who have PTSD are about three times more likely to use marijuana, and at least six times more likely to use addictive drugs such as cocaine [3]. PTSD patients are also three times more at risk of suicide [4]. In addition to patients, many others are indirectly affected by PTSD, including family members, friends, community members, colleagues, and employers.

Despite the importance of problems related to PTSD, little is known about effective policies for prevention or early diagnosis. There are three major barriers to developing effective policies. First, PTSD is a multi-organizational challenge [5]. In simple terms, patients' family members,

employers, colleagues, communities, and neighborhoods are often involved in cases of PTSD. At the macro level, larger entities such as the military, the healthcare system, the Department of Veterans Affairs (VA), and elected government officials are concerned and involved with the problems of PTSD. These stakeholders have different preferences and incentives. Focusing on one organization or a specific stage of patients' lives can result in shifting the burden to another organization rather than addressing the main roots of the problem. Most past policy studies of PTSD focus on one sector, usually a single organization such as the military. Second, similar to other dynamically complex problems, there are long delays between causes and effects. There is currently a huge number of unknown PTSD patients—those who have not yet shown any signs of the illness. Symptoms of PTSD are sometimes delayed for a decade [6], making current policies inadequate or ineffective. Finally, there are huge uncertainties about the prevalence of PTSD, the performance of screening procedures, and the accuracy of diagnosis [7]. Screening procedures are usually self-reported surveys, and the subjective answers can suffer from errors or be intentionally manipulated to avoid the stigma of the illness or malingering [5, 8].

Therefore, the importance and complexity of PTSD raise critical questions: What are the trends in the population of PTSD patients among military personnel and veterans in the postwar era? What policies can help mitigate the effects of PTSD? What are the healthcare cost implications of potential policies? Furthermore, the complexity of a dynamic problem such as PTSD, which includes potential delays between causes and effects, is beyond the understanding of the human brain [9, 10]. From this complexity emerges the use of systems science and simulation-based policy analysis [11], particularly system dynamics modeling [12, 13]. While systems models of different health-related problems have been developed [14-16], this study is the first to develop a system dynamics simulation model of PTSD, a model that includes both military personnel and veterans in a 'system of systems'. This is a novel aspect in our model since many policies implemented at the military level will potentially influence (and may have side effects on) veterans and the Department of Veterans Affairs. Calibrating the model to historical data, we estimated the future trends in the population with PTSD under various scenarios of US involvement in future wars. We further tested various policies for resource allocation, treatment and screening.

2. Study data and methods

We used time series datasets (2000-2014) from the Department of Defense, the Institute of Medicine, the Department of Veterans Affairs, and other sources (see Appendix 1) to set the baseline scenario and fit the model to the data. We also extensively used the literature as a source of model parameters (see Appendix 2). Our model presents the flow of people from recruitment into the military, from military service to the post-military stage, and from the post-military stage to death. The basic structure of the model is illustrated in Figure 1. The model contains two major sections (large dashed boxes): military and post-military. Each section has three stages (shown in rectangles) connected by ten potential pathways (arrows).

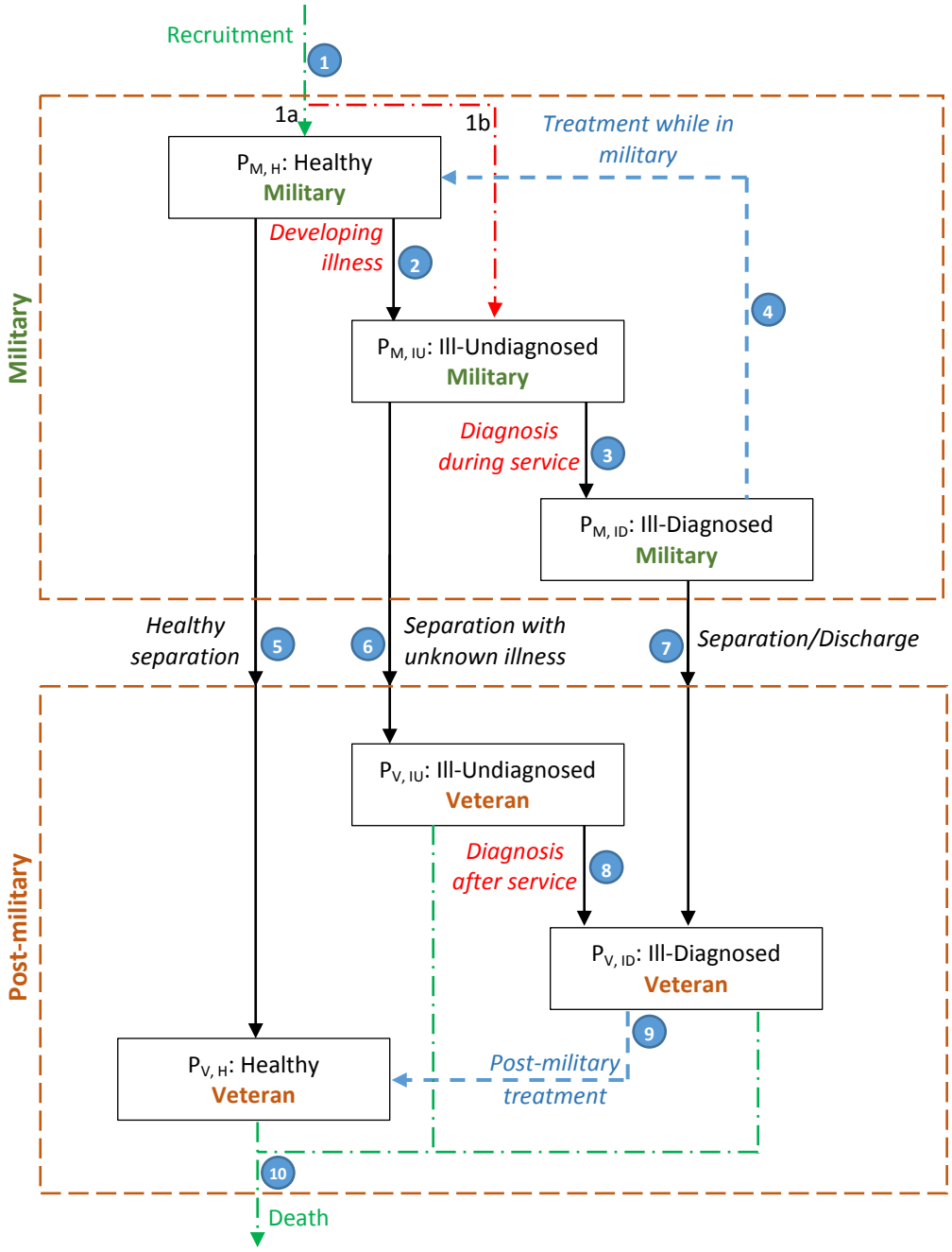


Figure 1: A simplified representation of the PTSD model of "Military/Post-military" system

Figure 1 represents different paths in this system. First, people enter the military through recruitment (path 1). The model divides people in the military into three categories: healthy, ill-undiagnosed, and ill-diagnosed. The majority of the new hires are PTSD-free and are in the healthy military category (path 1a). However, there is a chance of hiring people with a history of PTSD (path 1b). Healthy people move to ill-undiagnosed if they develop PTSD as a result of trauma (path 2). In this stage, they do not show any symptoms of PTSD. People move from ill-

undiagnosed to ill-diagnosed when they exhibit symptoms and are diagnosed (path 3). The population of ill-diagnosed may separate or get discharged, moving to post-military (path 7), or receive effective treatment and move back to the healthy sub-population (path 4). Given that the symptoms of PTSD are usually delayed, the ill-undiagnosed population might not show any symptoms while in the military; the problems may arise after their separation from the military (path 6). In each of these stages, a very small proportion of service personnel die due to PTSD-related or unrelated events; this is included in the model, but for the sake of simplicity it is not shown in Figure 1.

People leave the military and become veterans through three paths: healthy separation (path 5), separation with unknown illness (path 6), and separation/discharge with known illness (path 7). Similar to the military section, we divide the population in the post-military into healthy, ill-undiagnosed, and ill-diagnosed. The ill-undiagnosed veterans move to the ill-diagnosed sub-population when they are diagnosed with PTSD (path 8). Effective treatment in the post-military stage can move these ill individuals back into the healthy population (path 9). Finally, veterans leave the post-military stage when they die (path 10).

The model follows the described structure. For each state variable (box), the value is mathematically represented by the integration of inflow(s) minus outflow(s), following system dynamics methodology [9]. Detailed model formulations for each stage are fully documented in Appendix 3, and follow a set of minimum reporting requirements [17]. The model is calibrated to the data and unknown parameters are estimated—see Appendix 4 for more discussion and estimation results. Various sensitivity analyses showed that simulation results are robust for considerable changes in parameters and data errors (Appendix 5).

3. Study Results

While the developed model is complex and encompasses various details about military personnel, it is still a simplification of reality; as such, it should be carefully tested and validated for the purposes of the modeling project. To build confidence in the usefulness of the model, we conducted various tests, such as tests of structure and behavior validity [18], unit consistency, and equation robustness in extreme conditions [12]. Moreover, in the formulation of equations, we tested them against different input values to ensure that the logic portrayed in the data was represented [19]. The model was carefully calibrated to data using the partial model calibration method [20], which gives relatively more robust parameter estimates than other methods [21] [20]. And finally, behavior reproduction tests were conducted to evaluate the ability of the model to reproduce key behaviors observed in datasets (such as the trends of PTSD patients in the military, combat-related PTSD diagnosis rate in the military, PTSD patients in VA facilities, PTSD diagnosis rate in VA facilities, pre-2000 veterans with PTSD, Iraq and Afghanistan veterans with PTSD, PTSD costs in the military, and PTSD costs in VA facilities), which helped build further confidence in the model's usefulness [22]. For more information on model validation and sensitivity analysis of the estimated parameters, see Appendix 5.

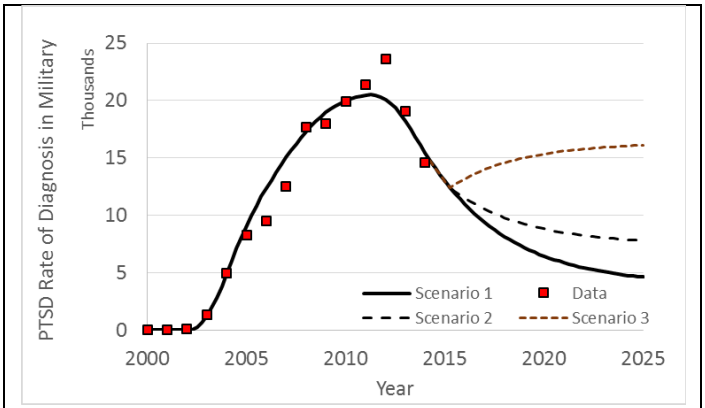
3.1. Base Run

We consider three scenarios for future engagements in wars:

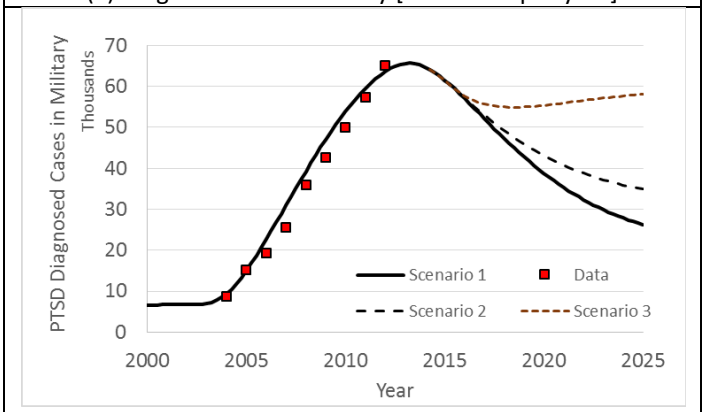
- Scenario 1 (S1): Minimum deployment to intense/combat zones (1% of military personnel); this is the current Obama administration policy for post-2015;
- Scenario 2 (S2): 2% deployment to intense/combat zones.
- Scenario 3 (S3): 5% deployment to intense/combat zones.

As a baseline for comparison, during 2001-2014, on average, 6.6% of US military personnel were deployed annually to combat zones, a rate that reached a maximum of 10.8% in 2008.

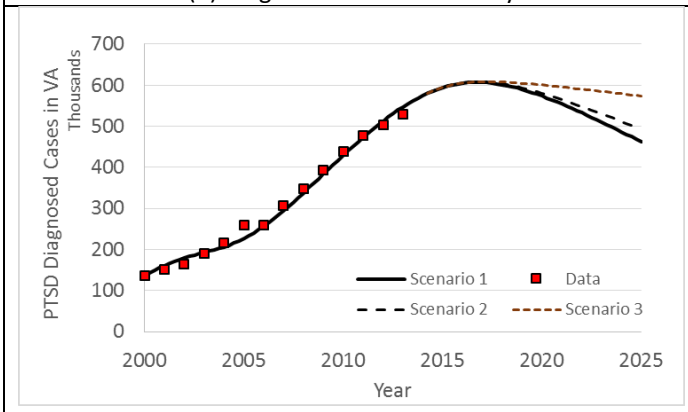
Figure 2 presents the base run simulations of the model for diagnosis rate in the military through the historical period starting in 2000 and then in the future through 2025. In addition to simulation outputs, historical data (2000-2014) is also presented in Figure 2. Figure 2 shows how closely the simulated results are fit with the historical data. Figure 2-a depicts the diagnosis rate in the military, which is annual new cases. As the figure shows, the number of new cases of PTSD has been declining since 2013, which is mainly due to decreasing the number of troops in Iraq and Afghanistan in recent years. The future trend, however, is very sensitive to US involvement in future wars, represented by the three scenarios (S1-S3). As depicted in Figure 2-b, the population of people with PTSD in the military significantly declines over time, reaching 28,000 in S1 and 36,000 in S2 in 2025. In S3, PTSD prevalence in the military increases greatly; diagnosed cases are estimated to be 58,000. Figure 2-c presents the PTSD population among veterans. Overall, the population of patients among veterans declines very slowly in



(a) Diagnosis rate in military [new cases per year]



(b) Diagnosed cases in military

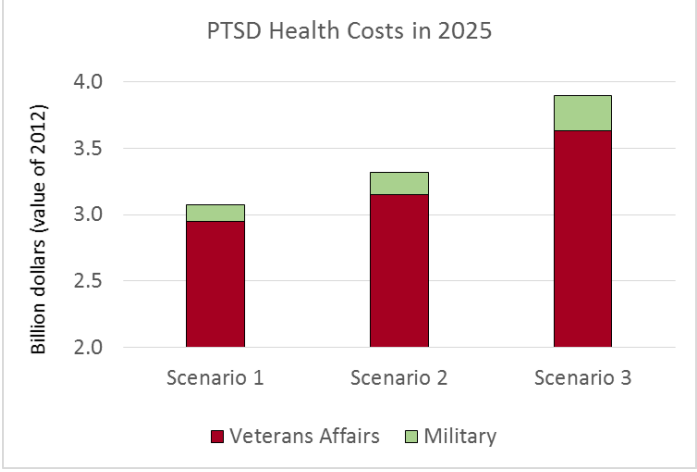


(c) Diagnosed cases in veterans

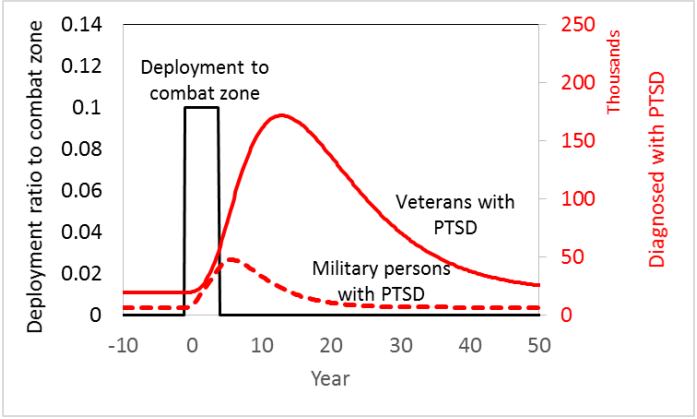
Figure 2: Base run simulations

comparison to the military, since people remain in the post-military stage for a long time (basically until death). Despite decreasing deployments, new cases will be diagnosed every year among veterans, since there is a delay between developing the illness and showing symptoms, revealing the long-lasting effects of wars. Under S3, which assumes more US troop involvement in future wars (equal to half of the involvement in Iraq and Afghanistan during 2000-2013), the population of patients among veterans stays relatively constant at around 600,000 over the next decade. Overall, Figure 2, shows relatively slow changes in the PTSD population, even when the number of new cases significantly declines, and also shows the sensitivity of the results to the scenarios of US involvement in future wars.

We also conducted two additional analyses with the model. First, we estimated direct annual costs of PTSD for the military and the VA healthcare systems (based on the dollar value in 2012), see Figure 3-a. Cost estimation was performed based on the assumption of constant costs per PTSD patient in the military and the VA over the next decade. Average cost per patient was extracted from the Institute of Medicine's report [7]. In S1, estimated healthcare costs for the military and VA were $125 million and $2.95 billion, respectively. In S2, these estimates rose to $164 million for the military and $3.15 billion for the VA. In S3, the estimates reached $264 million for the military and $3.63 billion for the VA.



(a) PTSD health costs in 2025, based on the dollar value in 2012



(b) A counterfactual analysis to measure the effects of a short-term war (between years zero and five) on PTSD prevalence in the military and among veterans.

Figure 3: Cost projection and inertia analysis in the system of military and post-military systems

Second, we ran a counter-factual analysis, from a steady state condition, presented in Figure 3-b. The simulation runs discussed above captured various factors that occur during the period 2000-2014. In this counterfactual, we used the estimated parameters from the model, but isolated all exogenous variables. The purpose of this simulation was to analyze the inertia in the system and measure how long it takes to vanquish the effects of a short 5-year war with 10% troop deployment (around the maximum deployment in Iraq). The results, presented in Figure 3-b, show the long delay required to vanquish the psychological effects of a war. Controlling for treatment, screening,

and training policies, Figure 3-b shows that it takes about 40-45 years for the veteran population to become PTSD-free. This represents the long-lasting effects of a war. Furthermore, Figure 3-b shows that the peak for the PTSD population among veterans emerges about six years after the war ends, due to various delays in the system, and the PTSD population is much higher among the veterans than in the military.

3.2. Policy Analysis

We analyzed all combinations of the three scenarios (S1-S3, discussed in Section 3.1) and five policy interventions using our model. For policy interventions, we had one control group (base run) and four policies. Similar to most other health interventions, these four policies focus on improving diagnosis, treatment effectiveness, and prevention. In Policy 1, improving diagnosis, the focus was on screening. We formulated this policy by doubling the screening sensitivity (the ratio of true positive to total positive cases). In Policy 2, the focus was on improving treatment, and we tested the effects of doubling the chance of effective treatment while PTSD patients are in the military. In Policy 3, we tested the effects of improvement in PTSD prevention. This policy represented effective training programs that might improve the resilience of military personnel to PTSD, by decreasing the likelihood of getting PTSD after trauma. We formulated a condition where resiliency to a trauma was doubled, meaning that the chance of developing PTSD after experiencing trauma was halved. In each of the policies, a single model input was changed; however, in Policy 4, we tested the combination of Policy 1, Policy 2, and Policy 3.

We used two major policy measures: PTSD prevalence and PTSD healthcare costs. Table 1 presents these policy measures for 2025. In Table 1-a, PTSD prevalence is reported. For each sector (military, veterans, and total system), 15 combinations of the three scenarios (S1-S3) and five policy interventions are presented. For example, in the military, under S1 (little involvement in future wars), PTSD prevalence was estimated to be 7% in the base run. If policies 1 or 2 were implemented, PTSD prevalence remained around 7%. However, with Policy 3, prevalence decreased to 5%, and with Policy 4 it further decreased to 4%. Table 1 is colored to emphasize the magnitude of the numbers and provide comparisons across all conditions (darker colors present larger numbers). A similar table is offered for healthcare costs in the military and the VA (Table 1-b).

Based on Table 1-a, it is notable that Policy 1 and Policy 2 had almost no effect compared to the corresponding values in the base run. The main reason is that with the current effectiveness of treatments (argued to be low), more screening only leads to finding more people who are PTSD positive. A sole focus on treatment does not help either, because most patients are late-diagnosed. The effects of Policy 3 (prevention) and Policy 4 (combination) were considerable for the military, especially under S3. It is important to note that the effects of Policy 3 and Policy 4 were still limited to the small population of military personnel with PTSD, and the VA will be still facing a large number of PTSD patients (between 10% and 11%).

Based on Table 1-b, Policy 1 increases healthcare costs in the military by 2025. In all conditions presented in Table 1-b, the numbers were higher than the corresponding base run simulation. Under this policy, since more people are screened, more PTSD positives are diagnosed. The policy results in finding more patients. However, without advancements in treatment, screening improvement only increases the demand for care. Thus, policy 1 can make us worse off in cost-related measures (PTSD costs in the military and the VA) and has almost no effect on PTSD prevalence. In terms of costs, the best policy seems to be a focus on treatment. This policy mainly discharges already diagnosed patients at a faster pace. Similar to the previous measure, the effects are limited to the military, and in the VA, costs change marginally and are still on the order of $3 billion. However, this policy also has a limited effect on PTSD prevalence, as many patients remained undiagnosed while in the military. Overall, Policy 3, which focuses on prevention by increasing the resiliency to PTSD, seems to be more effective in terms of decreasing both PTSD prevalence and costs.

Table 1: Simulation results for PTSD prevalence and healthcare costs in 2025 for the military, the VA, and the total military-VA system under different scenarios (S1-S3) times interventions (Policy 1 – Policy 4).

(a): PTSD prevalence in 2025 (%)

	Military			Veterans			Total System		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Base Run	7	11	21	10	10	11	9	10	12
Policy 1 (Screening)	7	10	20	9	10	11	9	10	12
Policy 2 (Treatment)	7	10	20	10	10	11	9	10	12
Policy 3 (Prevention)	5	9	13	9	10	10	9	10	11
Policy 4 (Mixed)	4	6	12	9	10	10	9	9	10

(b): PTSD healthcare costs in 2025 (in billions, based on the dollar value in 2012)

	Military			Veterans			Total System		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Base Run	0.13	0.16	0.26	2.95	3.15	3.63	3.08	3.31	3.89
Policy 1 (Screening)	0.18	0.25	0.41	3.11	3.33	3.90	3.29	3.58	4.31
Policy 2 (Treatment)	0.09	0.12	0.20	2.83	3.01	3.48	2.92	3.13	3.68
Policy 3 (Prevention)	0.11	0.14	0.19	2.88	3.06	3.33	2.99	3.20	3.52
Policy 4 (Mixed)	0.10	0.13	0.21	2.86	3.00	3.39	2.96	3.13	3.60

Note: For each sector (military, veterans, and total system), 15 combinations of the three scenarios (S1-S3) and five policy interventions are presented. One way to read the table is to compare the effects of policies in a scenario (e.g., S1). For example, in military, under S1 (little involvement in future wars), PTSD healthcare costs are estimated to be $0.13B in the base run. For policies 1 through 4, the PTSD healthcare costs are estimated to be $0.18B, $0.09B, $0.11B, and $0.10B, respectively. Another way to read the table is to compare different scenarios over a policy.

Overall, the changes in the numbers presented in Table 1 are much larger (under any policy),

when we move from S1 to S3, than the policy interventions themselves. While these policies can influence the PTSD prevalence and costs in the military, for the total system (military and VA), the effects of all policies are marginal. Comparing the policies, Policy 4, which is a combination of screening, treatment, and prevention, has a potential effect in mitigating PTSD.

4. Conclusions

We developed a systems model of the population of military personnel and veterans affected by post-traumatic stress disorder (PTSD) and compared the results with the actual data for 2000-2014. Then the model was used to forecast the trends for the next decade under several scenarios of US involvement in future wars. The major insights from the model are: 1) The population of patients and system costs are very sensitive to US involvement in future wars, and screening and treatment policy interventions have marginal effects in comparison; 2) In a very optimistic scenario, estimated PTSD prevalence among veterans in 2025 will be 10%; 3) During wars, resiliency-related policies are the most effective for decreasing PTSD; in a postwar period, there is no silver bullet to overcome the problem of PTSD; and 4) It takes a long time, on the order of 40 years, to vanquish the psychiatric consequences of a war.

These insights may help the military, the VA, and other government entities identify more effective strategies and also interact more effectively with one another. As discussed earlier, PTSD is a multi-organizational problem [5] and focusing on one organization or a specific stage of patients' lives can result in shifting the burden to another organization. We also would like to clarify that all costs estimations in the study are based on average expenditure per patients in military and VA healthcare facilities. The actual costs for each individual patient is much higher including the cascading effects of the illness on one's personal life [5]. The illness can result in social exclusion, job loss, drug and alcohol abuse, or family-related problems such as divorce [5].

Future studies could further validate our findings. Our work mainly describes the model as a flow process with few but relevant feedback loops. Future dynamic modeling studies could incorporate more feedback loop mechanisms. More dynamic factors can also be considered. For example, as changes occur in the system, treatment and screening may improve, which eventually will result in different behavior of the model outputs. We also followed the usual binary status to treat PTSD, but we acknowledge that mental illnesses almost always exist on a sliding scale, and to impose an on-off switch is relatively arbitrary. Despite these limitations, we hope the current study provides a first systematic step towards better understanding the consequences of PTSD policies.

Our model is fully documented not only for investigating various policies and analyzing the results over the long haul but also for further development and replications. The model is available to be run online at https://goo.gl/Dej8wL. The historical data and model's assumptions (embedded in model parameters and equations) are continually refined at the given web address.

Acknowledgements

This article is partly supported by the Office of the Assistant Secretary of Defense for Health Affairs, under Award No. W81XWH-12-0016. The US Army Medical Research Acquisition Activity (820 Chandler Street, Fort Detrick, MD 21702-5014), is the awarding and administering acquisition office.

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Appendices for the paper

A Simulation-Based Analysis of PTSD Prevalence among US Military Personnel and Veterans in 2025

APPENDIX 1: Data – Time Series

Table A1 provides a summary of time series data used in this study. We present more details about these data.

Table A1: Summary of time series used in the model

No	Variable	Values	Sources
Military and Veterans Population			
1	Military population	Figure A1	Institute of Medicine (2014) & D.o.D. (2015)
2	Troops in Iraq combat zone	Figure A1	D.o.D. (2012)
3	Troops in Afghanistan combat zone	Figure A1	D.o.D. (2012)
4	Military recruitment	Figure A2	D.o.D. (2014)
5	Military separation rate	Figure A2	Authors' estimation using [D.o.D. (2015) & D.o.D. (2013)] and D.o.D. (2014).
6	Veterans population	Figure A3	Institute of Medicine (2014) & Richardson and Waldrop (2003) and Bagalman (2014)
PTSD related variables			
7	PTSD diagnosed in military	Figure A4	Institute of Medicine (2014)
8	PTSD diagnosis rate in military		Institute of Medicine (2014) and Fischer (2014)
	8.1. Diagnosis rate of deployed	Figure A4	Fischer (2014)
	8.2. Diagnosis rate of not-deployed	Figure A4	Fischer (2014)
9	PTSD diagnosed veterans (all)	Figure A5	Institute of Medicine (2014), Rosenheck and Fontana (2007) and Hermes, Rosenheck, Desai, and Fontana (2012)
	9.1. Diagnosed; Iraq and Afghanistan veterans	Figure A5	Rosenheck and Fontana (2007) and Hermes et al. (2012)
	9.2. Diagnosed; pre-2000 era veterans	Figure A5	Rosenheck and Fontana (2007)
10	PTSD diagnosis rate of veterans	Figure A5	Institute of Medicine (2014)

Cost related variables			
11	PTSD costs in military	Figure A6	Institute of Medicine (2014)
12	PTSD costs in Veterans Affairs	Figure A6	Institute of Medicine (2014)

Military and Veterans Population

1. Military population
   Unit: Persons

   Description: The military includes active and reserve members.

   Values: Figure A1

   Source: Institute of Medicine (2014, p. 37) data for 2004-2012. The rest of the data are extracted from D.o.D. (2015).

2. Troops in Iraq combat zone
   Unit: Persons

   Description: The military personnel deployed to Iraq

   Values: Figure A1

   Source: The Department of Defense report, D.o.D. (2012)

3. Troops in Afghanistan combat zone
   Unit: Persons

   Description: Military personnel deployed to Afghanistan

   Values: Figure A1

   Source: The Department of Defense report, D.o.D. (2012)

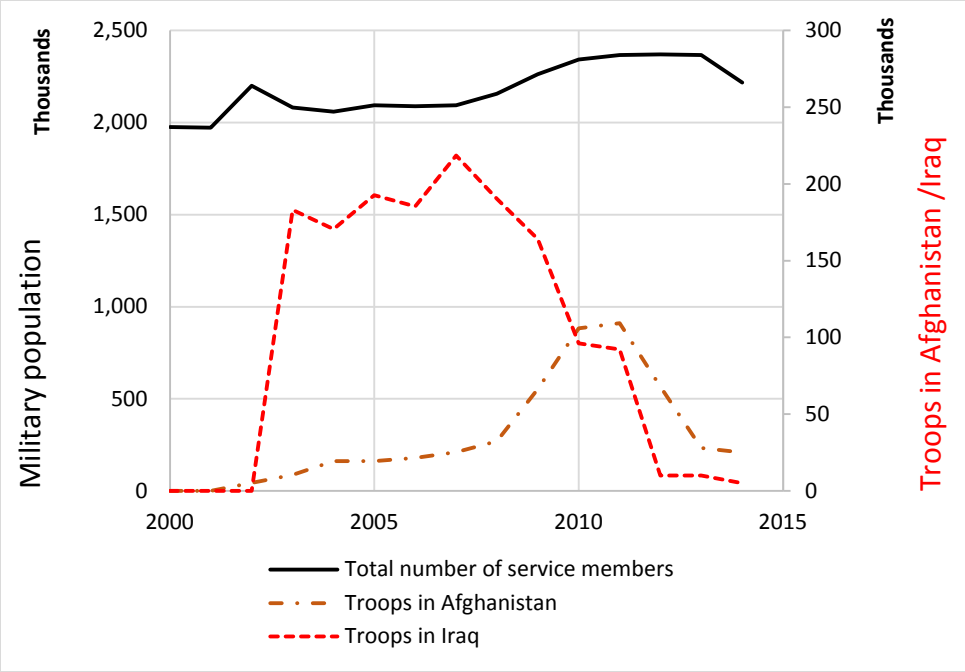


Figure A1: Total number of service members in the military (left axis) and deployment to Iraq and Afghanistan (right axis) for 2000-2014.

4. Military recruitment

   Unit: Persons/year

   Description: Annual recruitment for active and reserve personnel

   Values: Figure A2

   Source: Extracted from annual Department of Defense announcement for recruiting and retention for fiscal years of 2000 to 2014 D.o.D. (2014).

5. Military separation rate

   Unit: persons/year

   Description: Annual exit rate (separation) from the military

   Values: Figure A2

   Source: Authors' estimation from the military population and recruitment data [D.o.D. (2015) and D.o.D. (2013)] and D.o.D. (2014). For year t, we assume: Military

separation rate(t) = Recruitment(t) – [Military population(t+1)- Military population(t)].

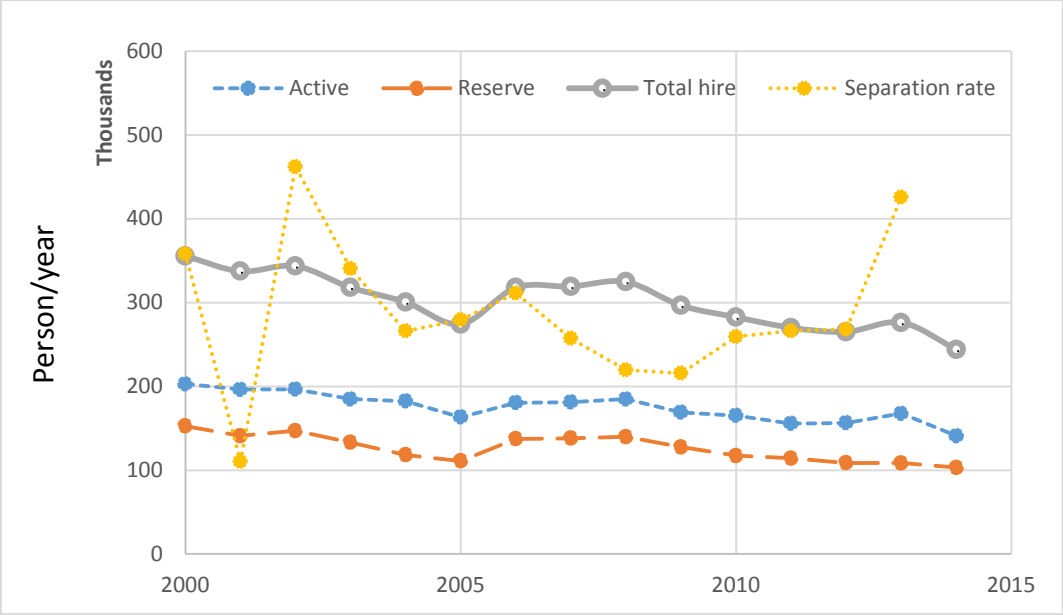


Figure A2: Military hiring rate (active, reserve, and total) and separation rate for 2000-2014

6. Veterans population

Unit: Persons

Description: All living veterans (18 years old and older)

Values: Figure A3

Source: Institute of Medicine (2014, p. 99) for 2010-2012. The rest of the data are extracted from Bagalman (2014) and Richardson and Waldrop (2003).

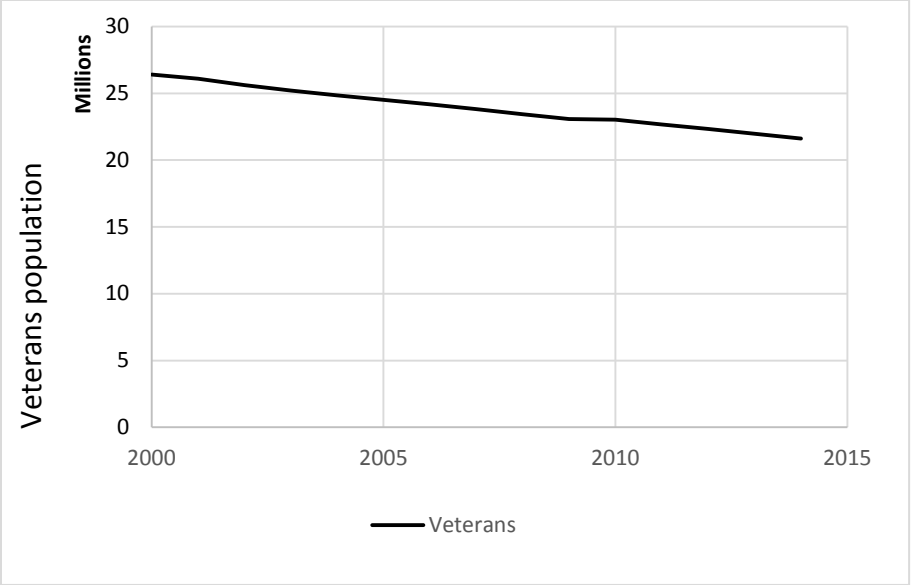


Figure A3: Total number of living veterans

PTSD related variables

7. PTSD diagnosed in military
   Unit: Persons

   Description: Number of the military service members who are diagnosed with PTSD. The Institute of Medicine considers a military person to have PTSD if during the year he/she had one inpatient stay or two outpatient visits, at least one day apart with the diagnosis.

   Values: Figure A4

   Source: Institute of Medicine (2014, p. 92) reports diagnosed military for 2004-2012.

8. PTSD diagnosis rate in military
   Unit: Persons/Year

   Description: Annual new diagnosis of PTSD in the military

   Values: Figure A4

Source: Institute of Medicine (2014, p. 37) reports PTSD diagnosed in the military for 2004-2012. The rest of the data are based on a congressional report by Fischer (2014) with minor adjustment to make consistent with the IOM report.

Sub-categories:

8.1. Diagnosis rate among the military members deployed to Iraq and Afghanistan, extracted from Fischer (2014).

8.2. Diagnosis rate among the military members not deployed, extracted from Fischer (2014).

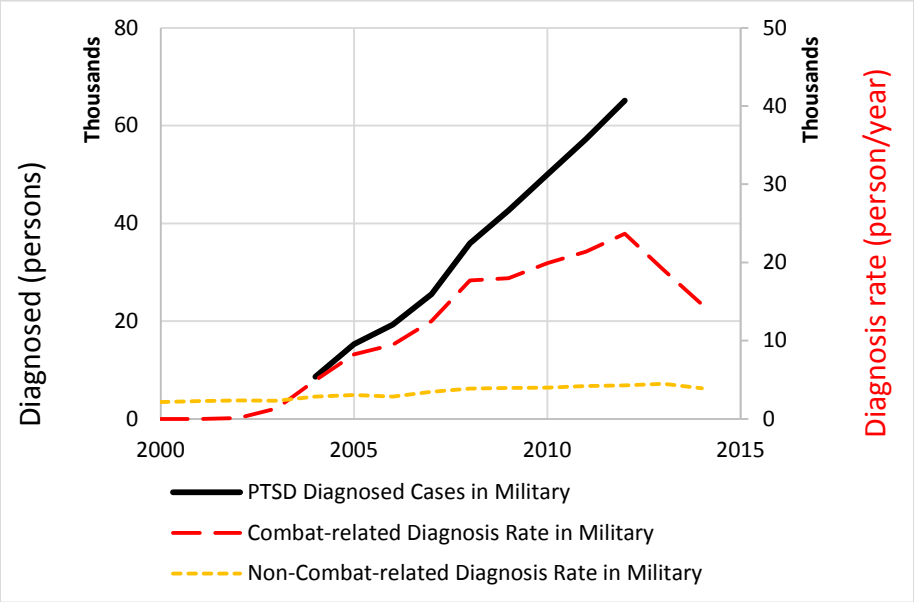


Figure A4: PTSD Diagnosed in the military and Diagnosis Rate (new cases)

9. PTSD diagnosed veterans

Unit: Persons

Description: Numbers of veterans receiving veteran affairs (VA) specialty mental health services for PTSD. The Institute of Medicine considers a veteran to have PTSD if during the year before he/she had one inpatient stay or two outpatient visits, at least one day apart with the diagnosis.

Values: Figure A5

Source: Institute of Medicine (2014, p. 41) reports data for years 2008 and 2013. The rest of the data are based on Rosenheck and Fontana (2007) and Hermes et al. (2012).

9.1. Veterans of Iraq and Afghanistan with PTSD

Source: Rosenheck and Fontana (2007) and Hermes et al. (2012)

9.2. Veterans of Pre-2000 era with PTSD

Note: We added up data on PTSD from wars prior to Afghanistan and from peace periods. A major portion of these data relates to Vietnam veterans.

Source: Data extracted from Exhibit 1 of Rosenheck and Fontana (2007).

10. PTSD diagnosis rate of veterans

Unit: Persons/Year

Description: Annual new diagnosis of PTSD in VA related facilities

Values: Figure A5

Source: Institute of Medicine (2014, p. 41) reports data for years 2008 and 2013.

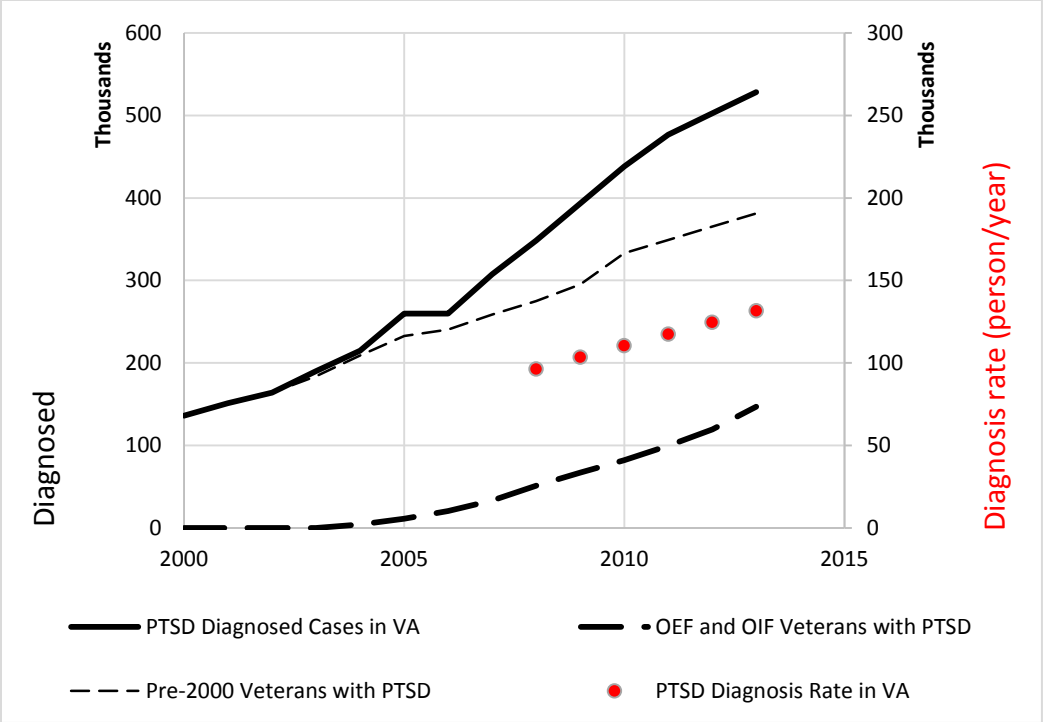


Figure A5: PTSD diagnosed in VA and diagnosis rate (new cases per year)

Cost related variables

11. PTSD costs in military

Unit: $

Description: This is only direct cost associated with a person under treatment in the military. The Institute of Medicine estimates this cost based on average costs per day for inpatient and outpatient visits related to PTSD and costs of buying drugs. The numbers are in real terms (inflation-adjusted) for the 2010 dollar value.

Values: Figure A6

Source: Institute of Medicine (2014, p. 92)

12. PTSD costs in Veterans Affairs

Unit: $

Description: This is only direct cost associated with a person under treatment in VA. The Institute of Medicine estimates this cost based on average costs per day for inpatient and outpatient visits related to PTSD and costs of buying drugs. The numbers are in real terms (inflation-adjusted) for the 2010 dollar value.

Values: Figure A6

Source: Institute of Medicine (2014, p. 99).

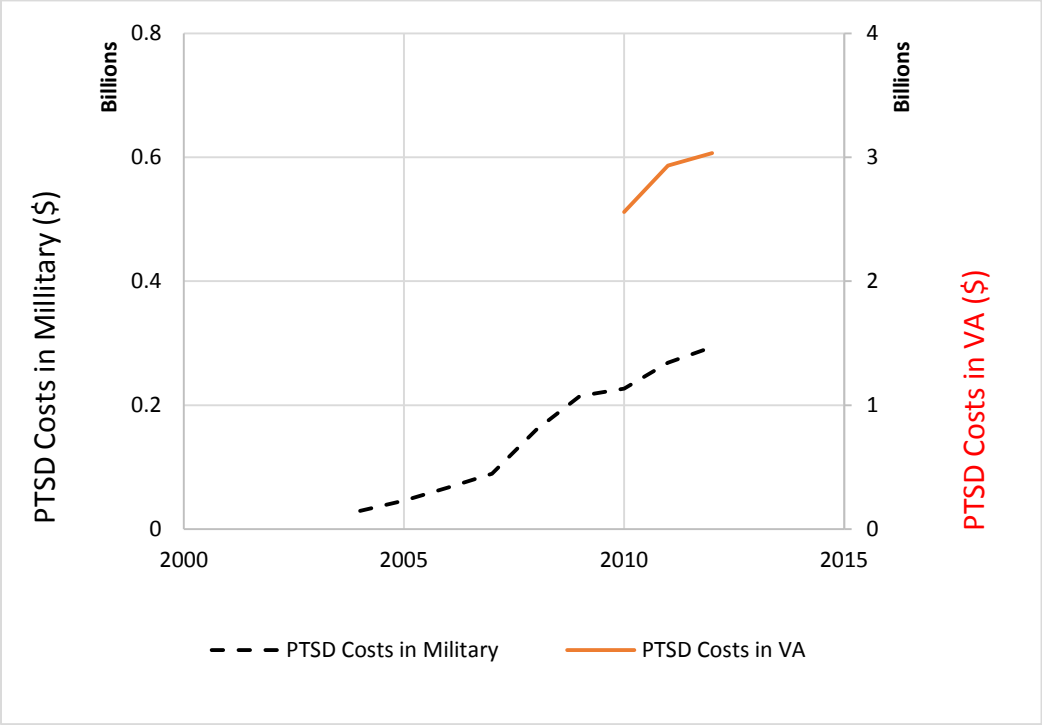


Figure A6: PTSD direct costs in the military and VA

APPENDIX 2: Data - Parameters

Parameters are assumed to be constant during the entire simulation run (2000-2025). Table A2 provides a summary of the parameters, their values, and sources. In following, we provide more details about these parameters.

Table A2: Summary of data used for model parameters

No	Parameters	Value	Sources
1	Annual separation ratio	12.5 %	Based on three estimates: DeFraites and Vythilingam (2011), Segal and Segal (2004, p. 10), and our estimation using Little's Law (Little, 1961).
	1.1. Separation ratio of ill-undiagnosed	18%	Estimated using item 1 of this table.
	1.2. Separation ratio of previously diagnosed	33%	DeFraites and Vythilingam (2011)
	1.3. Separation ratio of ill-diagnosed	20%	Dunbar (2013)
2	Probability of getting PTSD given a trauma	17%	Martin (2014)
3	Average number of traumas a deployed person experiences per year (traumas/year/person)	4.5	Weighted average of items 3.1 and 3.2 from Hoge et al. (2004)
	3.1. traumas/year/person in Iraq	6.21	Hoge et al. (2004)
	3.1. traumas/year/person in Afghanistan	3.02	Hoge et al. (2004)
4	Unhealthy recruitment ratio	0.01	Monahan, Hu, and Rohrbeck (2013)
5	Normal fractional rate of developing PTSD for non-combat related reasons	0.1%	Kilpatrick et al. (2013) and Organization for Economic Cooperation Development Staff (OECD) (2013).
6	Average cost per PTSD patient in military after 2012	$4,500	Institute of Medicine (2014)
7	Average cost per PTSD patient in VA after 2012	$6,244	Institute of Medicine (2014)

8	Fractional death rate for veterans (1/year)	0.023	Authors' estimation based on USA Social Security Administration (2010)
	8.1. Fractional death rate for Iraq and Afghanistan veterans	0.023	Authors' estimation based on USA Social Security Administration (2010)
	8.2. Fractional death rate for veterans non-deployed	0.023	Authors' estimation based on USA Social Security Administration (2010)
	8.3. Fractional death rate for pre-2000 veterans	0.030	Authors' estimation based on USA Social Security Administration (2010) and Richardson and Waldrop (2003)
9	Fractional death rate for military personnel	0.010	Authors' estimation based on USA Social Security Administration ("Actuarial Life Table," 2015) and (Waldman, 2015)

1. Annual separation ratios

Unit: 1/year

Description: This is the annual exit ratio from the military for different subpopulations, described in sections 1.1-1.3 below.

Value: 12.5%

Source: DeFraites and Vythilingam (2011) estimated annual separation rate of 15% for the military personnel population. This means every year about 15% of military personnel leave the military. If we take this estimation, the average duration of service should be slightly less than 7 years. This is not far from the argument of Segal and Segal (2004, p. 10). They state that the average length of service in the U.S. military is less than 10 years. We also used little's law (Little, 1961) to estimate the exit rates assuming relatively constant population in the military and a stable hiring rate (W=Average waiting time = Population/recruitment). This gives us W=7.8 years. Based on these sources, we assumed 8 years to be a reasonable estimate for the duration of service—for further validation, we conduct sensitivity analysis to build confidence in this assumption. This means the whole population of military personnel separates in the rate of 1/8=12.5%.

We used different methods to estimate separation ratios for different sub-categories:

1.1. Separation ratio of ill-undiagnosed: This is the population that has PTSD but not diagnosed. We assumed that the military personnel get deployed for about a year (or a year and a half) and they have some training before the deployment (Institute of Medicine, 2014, p. 40). So it would be reasonable to assume that on average for people who have just developed PTSD in a combat zone it takes about 5.5 years (8-2.5 years) to separate. Thus separation ratio for this sub-population would be roughly 18%.

1.2. Separation ratio of previously diagnosed: Based on DeFraites and Vythilingam (2011), 33% of the military personnel diagnosed with PTSD separate from the military in a year. However, a considerable portion of them (not necessarily all) are still ill and need care.

1.3. Separation ratio of ill-diagnosed: Following the quote by TSG Horoho: "The good news is 80% of those diagnosed with PTSD return to duty verifying what we in medicine have always known, PTSD is a treatable condition," (Dunbar, 2013). Accordingly, we believe it is reasonable to assume that 20% get discharged very soon as ill, and the rest of them (13%) get discharged in other forms, either as healthy, or ill-undiagnosed, in case they only discontinued their treatment.

2. Probability of getting PTSD given a trauma

   Unit: person/traumatic event

   Description: The average chance of developing PTSD if someone faces a trauma (with no special resiliency-related intervention)

   Value: 17%

   Source: Reported by Martin (2014)

3. Average number of traumas a deployed person experiences per year

   Unit: trauma/person/year

   Description: This value varies for different wars. Hoge et al. (2004) conducted a survey on selected infantry units of deployed military members in Iraq and Afghanistan to investigate the relation of exposure to combat and mental problems including PTSD. Their survey presents that traumatic exposure rate is 4.26 among 1,962 members in Afghanistan, and 8.74 among 1,709 members in Iraq. The weighted average (weighted based on the number of members) for traumatic events among all troops in Afghanistan and Iraq is 6.35. Length of deployment of multiple deploys, by branch of service and component as of 2010 is reported to be 16.9 months (Committee on the Assessment of the Readjustment Needs of Military Personnel, Base on Health of Select Populations, & Institute of Medicine, 2013, p. 41). Therefore, the average rate of trauma per person per year should be around 4.5 (6.34*12/16.9).

   Value: 4.5

   Source: (Hoge et al., 2004) and authors' estimations

3.1. Traumas/year/person in Iraq:

Hoge et al. (2004) estimated 8.74 traumas per person happens during the deployment in Iraq. Based on this, annual rate will be 6.21 per person.

3.2. Traumas/year/person in Afghanistan

Hoge et al. (2004) estimated 4.26 traumas per person happens during the deployment in Iraq. Based on this, annual rate will be 3.02 per person.

4. Unhealthy recruitment ratio

Unit: dimensionless

Description: This parameter represents the ratio of new hires who are assumed to be PTSD free (they may have other illnesses).

Value: 0.01

Source: Monahan et al. (2013) reports that the incidence of PTSD in recruit trainees among all of the service branches in 2000-2012 was 3.3 per 1,000 person-years. This will be the known cases. We assume that including unknown cases, 1% might be a reasonable estimate. Later in sensitivity analysis we change this parameter in a range of [0,0.05].

5. Normal fractional rate of developing PTSD for non-combat related reasons

Unit: 1/ year

Description: This is the chance that one develops PTSD while in the military for non-combat related reasons. We estimate this number from civilian lives, assuming that the average military personnel is as resilient as an average civilian and faces the same rate of traumatic conditions as a civilian experiences.

Lifetime prevalence of PTSD among U.S. adults is 7.8 percent (Kilpatrick et al., 2013). Life expectancy is about 80 years (Organization for Economic Cooperation Development Staff (OECD), 2013). We roughly estimate the chance of developing PTSD about 0.078 over 80 years, equal to 0.1% per year per person. Overall this number is very low in comparison to combat related traumas which makes the model not sensitive to our estimation.

Value: 0.1% /year

Source: Authors' estimation using (Kilpatrick et al., 2013) and (Organization for Economic Cooperation Development Staff (OECD), 2013)

6. Average cost per PTSD patient in military after 2012
   Unit: $/person

   Description: We conservatively take the 2012 value, assuming no further healthcare cost inflation.

   Value: $4,520 per diagnosed patient. This value is a weighted average of inpatient costs and outpatient costs.

   Source: Institute of Medicine (2014, p. 92)

7. Average cost per PTSD patient in VA after 2012
   Unit: $/person

   Description: We conservatively take the 2012 value, assuming no further healthcare cost inflation.

   Value: $6,244per diagnosed patient. This value is a weighted average of inpatient costs and outpatient costs.

   Source: Institute of Medicine (2014, p. 99)

8. Fractional death rate for veterans (death ratio per year for veterans)
   Unit: 1/year

   Description: We estimate this ratio based on the life expectancy of US citizens. Life expectancy of a 40 years old in the US is 40.4 years (death ratio: 1/40=0.025), and life expectancy of a 30 years old is 49.8 years (death ratio 1/50=0.02). We roughly estimate death ratio = 0.023 which also gives us a very good fit to data.

   Value: 0.023

   Source: Authors' estimation from data about life expectancy in the US using USA Social Security Administration (2010).

   8.1. Death ratio for Iraq and Afghanistan veterans: 0.023

   8.2. Death ratio for veterans not deployed: 0.023

   8.3. Death ratio for pre-2000 veterans: Median age of pre-2000 veterans was 57.4 in 2000 (Richardson & Waldrop, 2003). Life expectancy of a 60 years old is 22.8 (USA Social Security Administration, 2010). Therefore, we estimated death ratio to be 0.04 (1/25).

9. Fractional death rate for military personnel (death ratio per year for military personnel)
   Unit: 1/year

   Description: Military service period is about 8 years (see our estimation for the parameter *Annual separation ratio* (item one in this table). If in general people start their military service sometime between 18-25 years old and finish sometime between 25-32 years old, we can estimate the chance of death in this population from the civilians based on the data from USA Social Security Administration. The average chance of death in a window of eight year life in those young periods is about 1.0%. The number of fatality during service in the military is relatively very low. For example, total of 6,607 in Iraq and Afghanistan were killed (Waldman, 2015), the annual death of 0.02% for the whole military population.

   Value: 0.010

   Source: Authors' estimation from the data about life expectancy in the US using USA Social Security Administration ("Actuarial Life Table," 2015).

APPENDIX 3: Model Formulation

We list the model formulation in the same format that appears in Vensim (see the Vensim model, *PTSD_Simulation.mdl*, in the supplementary files). Model equations are listed for (a) simulation set-up, (b) model's main equations, and (c) experimental set-up.

(a) Simulation set-up

1. INITIAL TIME = 2000
   Units: year

2. FINAL TIME = 2025
   Units: year

3. TIME STEP = 0.25
   Units: year

4. SAVEPER = TIME STEP
   Units: year

(b) Model's main equations

5. "Healthy Military (PMH)"=
   INTEG (Recruitment of healthy-Developing illness in CZ-Developing illness not in CZ - PMH death rate-Rate of healthy separation, Initial PMH)

   Units: persons

6. "Healthy Veterans (PVH)"=
   INTEG (Rate of healthy separation+ Return of healthy veterans with PTSD history-Death rate of PVH, Initial PVH)

   Units: persons

7. "PM,ID: Ill-Diagnosed Military NotDeployed"=
   INTEG (Rate of diagnosis during service NotDeployed- PMIDn death rate-Separation of NotDeployed with PTSD -"Quitting treatment rate for not-deployed military", "initial PM,ID NotDeployed")

   Units: persons

8. "PM,ID: Ill-Diagnosed Military OEF & OIF"=
   INTEG ("Rate of diagnosis during service OEF & OIF"-PMID death rate-"Separation of OEF & OIF with PTSD"-"Quitting treatment rate for OEF & OIF in military", "initial PMID OEF&OIF")

Units: persons

9. "PM,IU: Ill-Undiagnosed Military NotDeployed"=
INTEG (Rate of developing illness NotDeployed+ Recruitment of unhealthy- PMIUn death ratio -Rate of diagnosis during service NotDeployed- Separation of NotDeployed with unknown illness, initial PMU NotDeployed)

Units: persons

10. "PM,IU: Ill-Undiagnosed Military OEF & OIF"=
INTEG ("Developing illness OEF&OIF"-PMIU death rate-"Rate of diagnosis during service OEF & OIF"-"Separation of OEF & OIF with unknown illness", "initial PMIU OEF&OIF")

Units: persons

11. "PV,ID: Ill-Diagnosed Veterans of Pre-2000"=
INTEG ("Rate of diagnosis after service of Pre-2000"-"Death rate of PV,ID of Pre-2000"-"Quitting treatment rate for Pre-2000", "initial PVID Pre-2000")

Units: persons

12. "PV,ID: Veterans NotDeployed"=
INTEG (Separation of NotDeployed with PTSD+ Rate of diagnosis after service NotDeployed -"Quitting treatment rate for not-deployed veterans"-"Death rate of PV,ID of NotDeployed", "initial PV,ID NotDeployed")

Units: persons

13. "PV,ID: Veterans of OEF & OIF"=
INTEG ("Rate of diagnosis after service OEF & OIF"+ "Separation of OEF & OIF with PTSD"-"Death rate of PV,ID of OEF&OIF"-"Quitting treatment rate for OEF & OIF veterans", "initial PVID OEF&OIF")

Units: persons

14. "PV,IU: Ill-Undiagnosed Veterans NotDeployed"=
INTEG (Separation of NotDeployed with unknown illness-"Death rate of PV,IU of Not deployed"-Rate of diagnosis after service NotDeployed+ Separation not deployed with Ineffective treatment, initial VIU NotDeployed)

Units: persons

15. "PV,IU: Ill-Undiagnosed Veterans OEF & OIF"=
INTEG "Separation of OEF & OIF with unknown illness"-"Death rate of PV,IU of OEF&OIF"-"Rate of diagnosis after service OEF & OIF"+ "Separation OEF & OIF with Ineffective treatment", "initial PVIU OEF&OIF")

Units: persons

16. "PV,IU: Ill-Undiagnosed Veterans of Pre-2000"=
    INTEG (-"Death rate of PV,IU of Pre-2000"-"Rate of diagnosis after service of Pre-2000", "initial VAU Pre-2000")

    Units: persons

17. "PM,ID: Ill-Diagnosed Military"=
    "PM,ID: Ill-Diagnosed Military NotDeployed"+"PM,ID: Ill-Diagnosed Military OEF & OIF"

    Units: persons

18. "initial PM,ID NotDeployed"=
    Initial rate of diagnosis of nondeployed/(Quitting treatment ratio in Military+ Separation ratio of people who have had PTSD)

    Units: persons

19. initial PMU NotDeployed=
    "initial PM,ID NotDeployed"*(Separation ratio of people who have had PTSD+ Quitting treatment ratio in Military)/Ratio revealing symptoms military

    Units: persons

20. Initial PMH=
    Initial military population - ("initial PMIU OEF&OIF"+ "initial PMID OEF&OIF"+ initial PMU NotDeployed +"initial PM,ID NotDeployed")

    Units: persons

21. Initial PVH=
    initial Veterans population-"initial PVID OEF&OIF"-"initial PVIU OEF&OIF"

    -initial VIU NotDeployed-"initial VAU Pre-2000"-"initial PVID Pre-2000"-"initial PV,ID NotDeployed"

    Units: persons

22. Post Treatment Stage Military NotDeployed=
    INTEG ("Quitting treatment rate for not-deployed military"-"Separation not-deployed veterans with unknown status but history of PTSD",0)

    Units: persons

23. "Post Treatment Stage Military OEF & OIF"=
    INTEG ("Quitting treatment rate for OEF & OIF in military"-"Separation OEF & OIF veterans with unknown status but history of PTSD", 0)

    Units: persons

24. "Rate of diagnosis during service OEF & OIF"=

"PM,IU: Ill-Undiagnosed Military OEF & OIF"*Ratio revealing symptoms military

Units: persons/year

25. Rate of diagnosis during service NotDeployed=
Min("PM,IU: Ill-Undiagnosed Military NotDeployed"/Min time to screen, A*"Rate of diagnosis during service OEF & OIF"+ B)

Units: persons/year

26. "(3) Rate of diagnosis during service"=
Rate of diagnosis during service NotDeployed+"Rate of diagnosis during service OEF & OIF"

Units: persons/year

27. Diagnosis multiplier=
(K*"PM,ID: Ill-Diagnosed Military")^Alpha

Units: Dmnl

28. Ratio revealing symptoms for pre2000 veterans=
Diagnosis multiplier*"Ratio revealing symptoms post-military"

Units: 1/year

29. "Rate of diagnosis after service of Pre-2000"=
"PV,IU: Ill-Undiagnosed Veterans of Pre-2000"*Ratio revealing symptoms for pre2000 veterans

Units: persons/year

30. "Rate of diagnosis after service OEF & OIF"=
"PV,IU: Ill-Undiagnosed Veterans OEF & OIF"*"Ratio revealing symptoms post-military"

Units: persons/year

31. Rate of diagnosis after service NotDeployed=
"PV,IU: Ill-Undiagnosed Veterans NotDeployed"*"Ratio revealing symptoms post-military"

Units: persons/year

32. "(8) Rate of diagnosis after service"=
"Rate of diagnosis after service of Pre-2000"+"Rate of diagnosis after service OEF & OIF"+ Rate of diagnosis after service NotDeployed

Units: persons/year

33. "Death rate of PV,ID of NotDeployed"=
"Death ratio for PV,ID NotDeployed"*"PV,ID: Veterans NotDeployed"

Units: persons/year

34. "Death rate of PV,ID of OEF&OIF"=
"Death ratio for PV,ID of Veterans of OEF & OIF"*"PV,ID: Veterans of OEF & OIF"

Units: persons/year

35. "Death rate of PV,ID of Pre-2000"=
"Death ratio for PV,ID Pre-2000"*"PV,ID: Ill-Diagnosed Veterans of Pre-2000"

Units: persons/year

36. "Death rate of PV,IU of Not-deployed"=
"Death ratio for PV, IU NotDeployed"*"PV,IU: Ill-Undiagnosed Veterans NotDeployed"

Units: persons/year

37. "Death rate of PV, IU of OEF&OIF"=
"Death ratio for PV, IU of Veterans of OEF & OIF"*"PV, IU: Ill-Undiagnosed Veterans OEF & OIF"

Units: 1/year

38. "Death rate of PV,IU of Pre-2000"=
"Death ratio for PV, IU Pre-2000"*"PV,IU: Ill-Undiagnosed Veterans of Pre-2000"

Units: 1/year

39. Death rate of PVH=
Death ratio for PVH*"Healthy Veterans (PVH)"

Units: 1/year

40. PMH death rate=
Death ratio in military*"Healthy Military (PMH)"

Units: persons/year

41. PMID death rate=
Death ratio in military*"PM,ID: Ill-Diagnosed Military OEF & OIF"

Units: persons/year

42. PMIU death rate=
Death ratio in military*"PM,IU: Ill-Undiagnosed Military OEF & OIF"

Units: persons/year

43. PMIUn death ratio=
Death ratio in military*"PM,IU: Ill-Undiagnosed Military NotDeployed"

Units: persons/year

44. PMIDn death rate=
    Death ratio in military*"PM,ID: Ill-Diagnosed Military NotDeployed"

    Units: persons/year

45. total death rate in military=
    PMH death rate+ PMID death rate+ PMIU death rate+ PMIUn death ratio+ PMIDn death rate

    Units: persons/year

46. PMH in CZ=
    "Healthy Military (PMH)"*"Ratio deployed to combat zone (CZ)"

    Units: (Trauma/persons)/year

47. Trauma experienced by PMH=
    PMH in CZ*Trauma rate per year per person in CZ

    Units: Trauma/year

48. Chance of developing PTSD given CZ trauma=
    Normal chance of developing PTSD in CZ/Resiliency effect

    Units: persons/Trauma

49. Chance of developing PTSD in NON CZ=
    Normal chance of developing PTSD in NON CZ/Resiliency effect

    Units: 1/year

50. Developing illness in CZ=
    Trauma experienced by PMH*Chance of developing PTSD given CZ trauma

    Units: persons/year

51. PMH not in CZ=
    "Healthy Military (PMH)"*(1-"Ratio deployed to combat zone (CZ)")

    Units: persons

52. Developing illness not in CZ=
    Chance of developing PTSD in NON CZ*PMH not in CZ

    Units: persons/year

53. "Developing illness OEF&OIF"=
    Developing illness in CZ

Units: 1/year

54. Separation of NotDeployed with unknown illness=
"PM,IU: Ill-Undiagnosed Military NotDeployed"*Separation ratio of ill undiagnosed service members

Units: persons/year

55. "Separation of OEF & OIF with unknown illness"=
"PM,IU: Ill-Undiagnosed Military OEF & OIF"*Separation ratio of ill undiagnosed service members

Units: persons/year

56. Separation of NotDeployed with PTSD=
Separation ratio of people who have had PTSD*"PM,ID: Ill-Diagnosed Military NotDeployed"

Units: persons/year

57. "Separation of OEF & OIF with PTSD"=
Separation ratio of people who have had PTSD*"PM,ID: Ill-Diagnosed Military OEF & OIF"

Units: persons/year

58. Ill exits from military=
Separation of NotDeployed with unknown illness +"Separation of OEF & OIF with unknown illness" +Separation of NotDeployed with PTSD +"Separation of OEF & OIF with PTSD"

Units: 1/year

59. "Separation not-deployed veterans with unknown status but history of PTSD" =
Post Treatment Stage Military NotDeployed*Separation ratio with history of PTSD

Units: persons/year

60. "Separation OEF & OIF veterans with unknown status but history of PTSD" =
"Post Treatment Stage Military OEF & OIF"*Separation ratio with history of PTSD

Units: persons/year

61. Separation with histroy of PTSD but current unknown status=
"Separation not-deployed veterans with unknown status but history of PTSD" +"Separation OEF & OIF veterans with unknown status but history of PTSD"

Units: persons/year

62. "Estimate of rate of healthy separation for pre-2014"=

Max (0,DELAY1i(exit data(Time),data adjustment delay,Initial rate of healthy separation)-Ill exits from military-Separation with histroy of PTSD but current unknown status- total death rate in military)

Units: persons/year

Comment: The data reports final year death numbers. With a half a year delay we assume death is uniformly distributed over the year.

63. "PM,IU: Ill-Undiagnosed Military"=
"PM,IU: Ill-Undiagnosed Military NotDeployed"+"PM,IU: Ill-Undiagnosed Military OEF & OIF"

Units: persons

64. Service members with PTSD=
"PM,ID: Ill-Diagnosed Military" +"PM,IU: Ill-Undiagnosed Military"

Units: persons

65. Service members with history of PTSD and current unknown status=
Post Treatment Stage Military NotDeployed+"Post Treatment Stage Military OEF & OIF"

Units: persons

66. Total number of service members=
"Healthy Military (PMH)"+Service members with PTSD+ Service members with history of PTSD and current unknown status

Units: persons

67. Rate of healthy separation=
IF THEN ELSE(Time>2014 , "Estimate of rate of healthy separation for post-2014", "Estimate of rate of healthy separation for pre-2014")

Units: persons/year

68. Total exit from military=
Rate of healthy separation+ Ill exits from military+ Separation with history of PTSD but current unknown status+ total death rate in military

Units: persons/year

69. "Estimate of rate of recruitment for post-2014"=
max(0,Military size gap/Time to fill the gap+ Total exit from military)

Units: persons/year

70. Healthy separation not deployed with history of PTSD=

ratio of effective treatment*"Separation not-deployed veterans with unknown status but history of PTSD"

Units: persons/year

71. "Healthy separation OEF & OIF with history of PTSD"=
ratio of effective treatment*"Separation OEF & OIF veterans with unknown status but history of PTSD"

Units: persons/year

72. PTSD Cost for Diagnosed Military NotDeployed=
"PM,ID: Ill-Diagnosed Military NotDeployed"*PTSD Cost per Diagnosed Military(Time)

Units: dollar

73. “PTSD Cost for Diagnosed Military OEF & OIF"=
"PM,ID: Ill-Diagnosed Military OEF & OIF"*PTSD Cost per Diagnosed Military (Time)

Units: dollar

74. PTSD Cost for Diagnosed Veterans NotDeployed=
PTSD Cost per Diagnosed Veterans (Time)*"PV,ID: Veterans NotDeployed"

Units: dollar

75. "PTSD Cost for Diagnosed Veterans OEF & OIF"=
PTSD Cost per Diagnosed Veterans (Time)*"PV,ID: Veterans of OEF & OIF"

Units: dollar

76. "PTSD Cost for Diagnosed Veterans Pre-2000"=
PTSD Cost per Diagnosed Veterans (Time)*"PV,ID: Ill-Diagnosed Veterans of Pre-2000"

Units: dollar

77. PTSD Cost in Military=
"PM,ID: Ill-Diagnosed Military"*PTSD Cost per Diagnosed Military (Time)

Units: dollar

78. "PV,ID: Ill-Diagnosed Veterans"=
"PV,ID: Ill-Diagnosed Veterans of Pre-2000"+"PV,ID: Veterans of OEF & OIF"+"PV,ID: Veterans NotDeployed"

Units: persons

79. PTSD Cost in VA=
PTSD Cost per Diagnosed Veterans (Time)*"PV,ID: Ill-Diagnosed Veterans"

Units: dollar

80. "PV,IU: Ill-Undiagnosed Veterans"=
"PV,IU: Ill-Undiagnosed Veterans of Pre-2000"+"PV,IU: Ill-Undiagnosed Veterans OEF & OIF"+ "PV,IU: Ill-Undiagnosed Veterans NotDeployed"

Units: persons

81. Veterans with PTSD=
"PV,ID: Ill-Diagnosed Veterans"+"PV,IU: Ill-Undiagnosed Veterans"

Units: persons

82. Total number of veterans=
"Healthy Veterans (PVH)"+Veterans with PTSD

Units: persons

83. PTSD prevalence among Veterans=
Veterans with PTSD/Total number of veterans

Units: Dmnl

84. PTSD prevalence in Military=
Service members with PTSD/Total number of service members

Units: Dmnl

85. "Quitting treatment rate for not-deployed military"=
Quitting treatment ratio in Military*"PM,ID: Ill-Diagnosed Military NotDeployed"

Units: 1/year

86. "Quitting treatment rate for not-deployed veterans"=
Quitting treatment ratio for veterans*"PV,ID: Veterans NotDeployed"

Units: persons/year

87. "Quitting treatment rate for OEF & OIF in military"=
Quitting treatment ratio in Military*"PM,ID: Ill-Diagnosed Military OEF & OIF"

Units: persons/year

88. "Quitting treatment rate for OEF & OIF veterans"=
Quitting treatment ratio for veterans*"PV,ID: Veterans of OEF & OIF"

Units: persons/year

89. "Quitting treatment rate for Pre-2000"=
Quitting treatment ratio for veterans*"PV,ID: Ill-Diagnosed Veterans of Pre-2000"

Units: persons/year

90. Rate of developing illness NotDeployed=
Developing illness not in CZ

Units: persons/year

91. Recruitment of healthy=
(1-Unealthy recruitment ratio)*Recruitment

Units: persons/year

92. Recruitment of unhealthy=
Unhealthy recruitment ratio*Recruitment

Units: persons/year

93. Separation of healthy Veterans with history of PTSD=
"Healthy separation OEF & OIF with history of PTSD"+ Healthy separation not deployed with history of PTSD

Units: persons/year

94. Return of healthy veterans with PTSD history=
Separation of healthy Veterans with history of PTSD+ "Quitting treatment rate for OEF & OIF veterans"

Units: persons/year

95. Separation not deployed with Ineffective treatment=
(1-ratio of effective treatment)*"Separation not-deployed veterans with unknown status but history of PTSD"

Units: persons/year

96. "Separation OEF & OIF with Ineffective treatment"=
(1-ratio of effective treatment)*"Separation OEF & OIF veterans with unknown status but history of PTSD"

Units: persons/year

97. Separation of Ill Undiagnosed Veterans with history of PTSD=
"Separation OEF & OIF with Ineffective treatment"+ Separation not deployed with Ineffective treatment

Units: persons/year

(c) Experimental set-up

98. Resiliency effect=

Normal Resiliency*max (0, 1+Smooth (step(Percent Change in Resiliency/100,Policy implementation time), Time to implement policy))

Units: Dmnl

99. Ratio revealing symptoms military=
Normal Ratio revealing symptoms military* max(0,1+Smooth(step(Percent Change in Screening/100,Policy implementation time),Time to implement policy))

Units: 1/year

100. Quitting treatment ratio in Military=
Normal quitting ratio in Military*max(0,1+Smooth(step(Percent Change in Treatment in Military/100,Policy implementation time),Time to implement policy))

Units: 1/year

101. Deployment to a hypothetical war=
Intensity of a hypothetical war in comparison to Iraq*Trauma multiplier in Iraq*"Deployment during Iraq war (data)"(Time-"Time for an Iraq-like war")

Units: Dmnl

102. Steady state deployment=
IF THEN ELSE (Time>2015, Intensity in steady state in comparison to Iraq*Deployment ratio in Iraq during the war*Trauma multiplier in Iraq,0)

Units: Dmnl

103. "Deployment to CZ-like areas post-2014"=
Deployment to a hypothetical war+ Steady state deployment

Units: persons

104. Desired number of service members=
Total service members in 2014

Units: Dmnl

105. "Ratio deployed to combat zone (CZ)"=
IF THEN ELSE(Time<=2015,"Deployment to CZ areas pre-2014 (OEF & OIF)" (Time),"Deployment to CZ-like areas post-2014")

Units: Dmnl

106. "Estimate of rate of healthy separation for post-2014"=
"Healthy Military (PMH)"*Separation ratio of healthy service members

Units: persons/year

107. "Estimate of rate of recruitment for post-2014"=
max(0,Military size gap/Time to fill the gap+Total exit from military)

Units: persons/year

108. Military size gap=
Desired number of service members-Total number of service members

Units: year

109. Recruitment=
IF THEN ELSE(Time>2014,"Estimate of rate of recruitment for post-2014","Recruitment data pre-2014"(Time))

Units: persons/year

APPENDIX 4: Model Calibration

In any modeling, the overall goal is to estimate as many parameters as possible directly from data. But sometimes there are some parameters for which data are not gathered, reliable data are not available, or we could not find them. In these situations, we can statistically calibrate the model to data by estimating the unknown parameters.

In simple words, calibration is about using statistical methods to estimate parameter values for which we do not have data. It is important to conduct sensitivity analysis for estimated parameters, examining the model's robustness to changes in the estimations.

We conduct one of the most accurate calibration procedures, partial model calibration/testing (Homer, 2012). In the partial model calibration, different pieces of the model are separately calibrated. This method is known to provide relatively robust estimates and decrease the chances of over-fitting the model. It also helps understand which parts of the model are better representative of the reality and which parts are producing more errors.

4.1. Unknown parameters

Table A3 presents estimated parameters through calibration as well as the respective calibration steps. Overall, we have conducted six different calibration procedures (calibration procedures 1-6) for the total of eight unknown parameters. Sensitivity of our results to parameter estimations is presented in APPENDIX 5.

Table A3: Estimated (unknown) parameters in the model

No	Parameter	Value	Calibration step
1	Quitting treatment ratio in military	0.125	Calibration procedure 1
2	Quitting treatment ratio in VA	0.145	Calibration procedure 2
3	Ratio revealing symptoms in military	0.043	Calibration procedure 3
4	Ratio revealing symptoms for veterans	0.103	Calibration procedure 4
5	Effects of Iraq/Afghanistan wars on revealing symptoms for pre-2000 $x = (K*P_{M,}ID)^{\alpha}$	K= 1.38E-06 α = 0.4959	Calibration procedure 5

6	Rate of PTSD diagnosis for non-combat related reasons		Calibration procedure 6
	$y = y_c + a$*Rate of diagnosis OEF & OIF	$y_c = 2267.8$	
	$y < PM,IU$	$a = 0.0936$	

1. Quitting treatment ratio in military

   Unit: 1/year

   Description: Since there is no reliable data on effective treatment (Institute of Medicine, 2014), we focus on the number of people who stop receiving treatment. This ratio presents the portion of the military personnel who were receiving PTSD treatment in the previous time period (*t-1*), and are no longer under treatment (at time *t*). The degree of freedom (DOF) in this producer is one (described in more detail in calibration procedure 1), which means we have a highly accurate estimation.

   Source: Calibration procedure 1 (DOF=1)

   Value: 0.1347

2. Quitting treatment ratio in VA

   Unit: 1/year

   Description: Since there is no reliable data on effective treatment (Institute of Medicine, 2014, p. 33), we focus on the number of people who stop receiving treatment. This ratio is in fact veterans who were receiving PTSD treatment in VA facilities in the previous time period (*t-1*), and are no longer under treatment (at time *t*). Similar with the previous parameter, the DOF in this producer is one (described in more detail in calibration procedure 2), which means we have a highly accurate estimation.

   Source: Calibration procedure 2 (DOF=1).

   Value: 0.1457

3. Ratio revealing symptoms in military

   Unit: 1/year

   Description: Not all military members with PTSD show symptoms while serving in the military. There is no data on how many people have PTSD and are undiagnosed.

Thus, we estimated the rate at which undiagnosed military personnel turn to diagnosed military personnel through calibration.

Source: Calibration procedure 3 (DOF=1).

Value: 0.0415

4. Ratio revealing symptoms post-military (Iraq and Afghanistan)

Unit: 1/year

Description: Many veterans who have PTSD gradually show their symptoms of illness. We estimated at rate at which undiagnosed veterans turn to diagnosed veterans through calibration.

Source: Calibration procedure 4 (DOF=1)

Value: 0.1001

5. Effects of Iraq/Afghanistan wars on revealing symptoms for pre-2000 veterans

Unit: 1/year

Description: Ratio of revealing symptoms for pre-2000 veterans is not necessarily the same as the ratio for more recent wars. Some veterans who served in the military before 2000 and developed PTSD may show symptoms of illness after 2000. Anecdotal evidence and the paper by Hermes et al. (2012) suggest that the number of Vietnam veterans with PTSD is still increasing. One argument is that the war in Iraq and Afghanistan had triggered old memories exacerbating the situation of these veterans. This is one of the reasons we may see a growth in PTSD of pre-2000 veterans. Accordingly, we assumed:

Ratio of revealing symptoms post-military for pre-2000 wars =

*Ratio of revealing symptoms post-military * Effects of Iraq/Afgh wars =*

*Ratio of revealing symptoms post-military * [K*$P_{M,}$ID $^{\alpha}$]*

In this formulation, the term [K*$P_{M,}$ID $^{\alpha}$] is used to represent the multiplier effect of recent wars. The logic is that with more PTSD cases from recent wars, we will hear proportionally more news about PTSD which affects new diagnosis in an increasing but declining slop.

Source: Calibration procedure 5 (DOF=2)

Values: K= 1.14E-3; $\alpha = 0.51$

6. Rate of PTSD diagnosis for non-combat related reasons

   Unit: Persons/year

   Description: Ratio of revealing symptoms for people not deployed have been increasing. We presented this with a constant parameter (representing issues unrelated to wars) plus a linear term representing the growth trend. This growth trend is partially due to more screening and more attention to PTSD or hiring individuals with illness.

   Rate of PTSD diagnosis for non-combat related reasons =

   $= y_c + a$*Rate of diagnosis OEF & OIF + $b < P_{M, IU}$

   Source: Calibration procedure 6 (DOF=2)

   Values: $y_c = 2267.8$; $a = 0.0936$

4.2. Calibration procedures:

Calibration procedure 1:

- Input: *Rate of diagnosis [of PTSD] in Military* (
- Table A1, item 8.1)*, Separation ratio of ill-diagnosed* (Table A2, item 1-3), and *fractional death rate for military personnel* (Table A2, item 9).
- Payoff function: maximize the fit between the data and simulation of $P_{M,ID}$.
- Outcomes: the only unknown parameter, *Quitting treatment ratio in military* (Table A3, item 1).
- DOF: 1

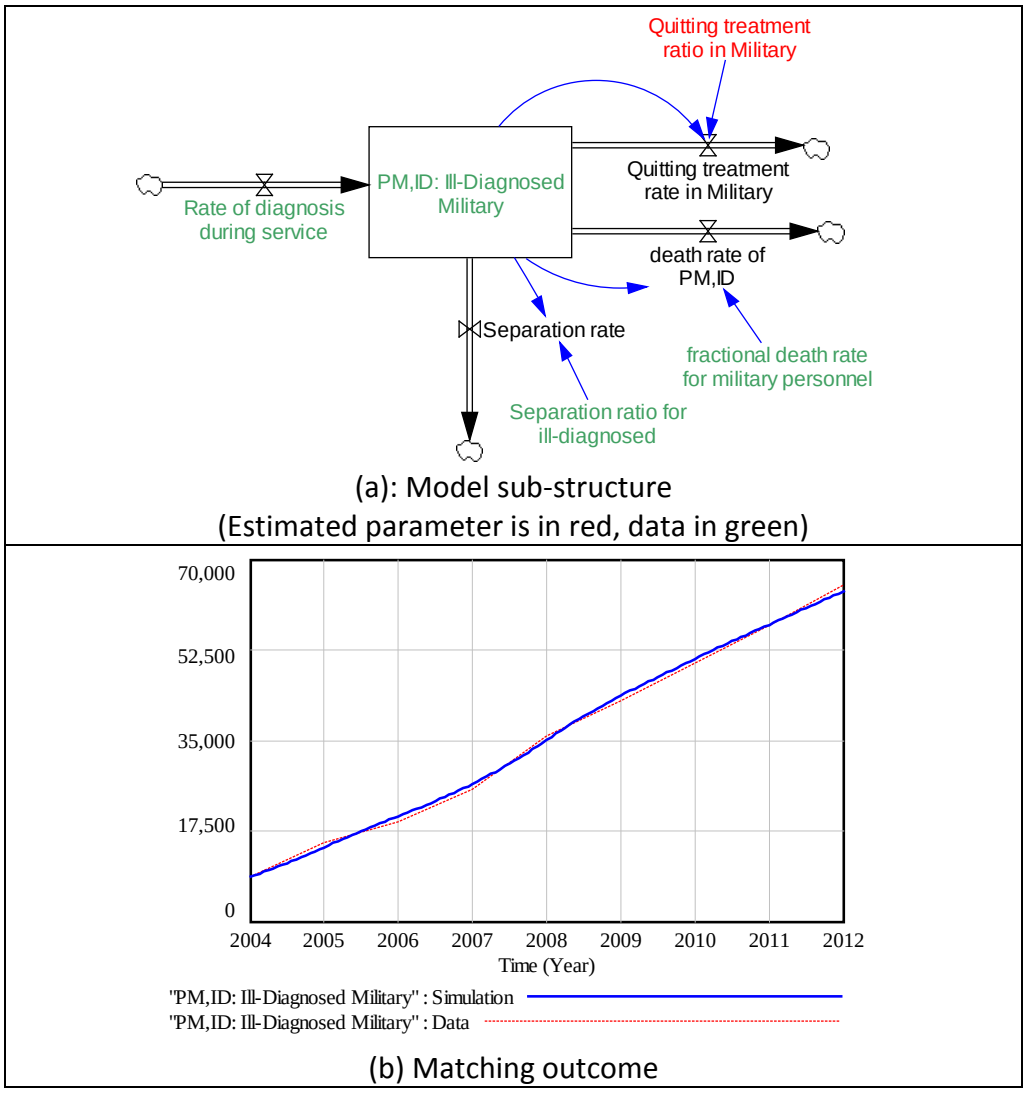


Figure A7: Calibration procedure 1 including model sub-structure (a), and the matching outcome (b).

Calibration outcome: *Quitting treatment ratio in military* = 0.125

Calibration procedure 2:

- Input: *Rate of diagnosis in VA* (
- Table A1, item 10), *fractional death rate for veterans* (Table A2, item 8).
- Payoff function: maximize the fit between the data and simulation of $P_{V,ID}$.
- Outcomes: the only unknown parameter, *Quitting treatment ratio in VA* (Table A3, item 2)
- DOF: 1

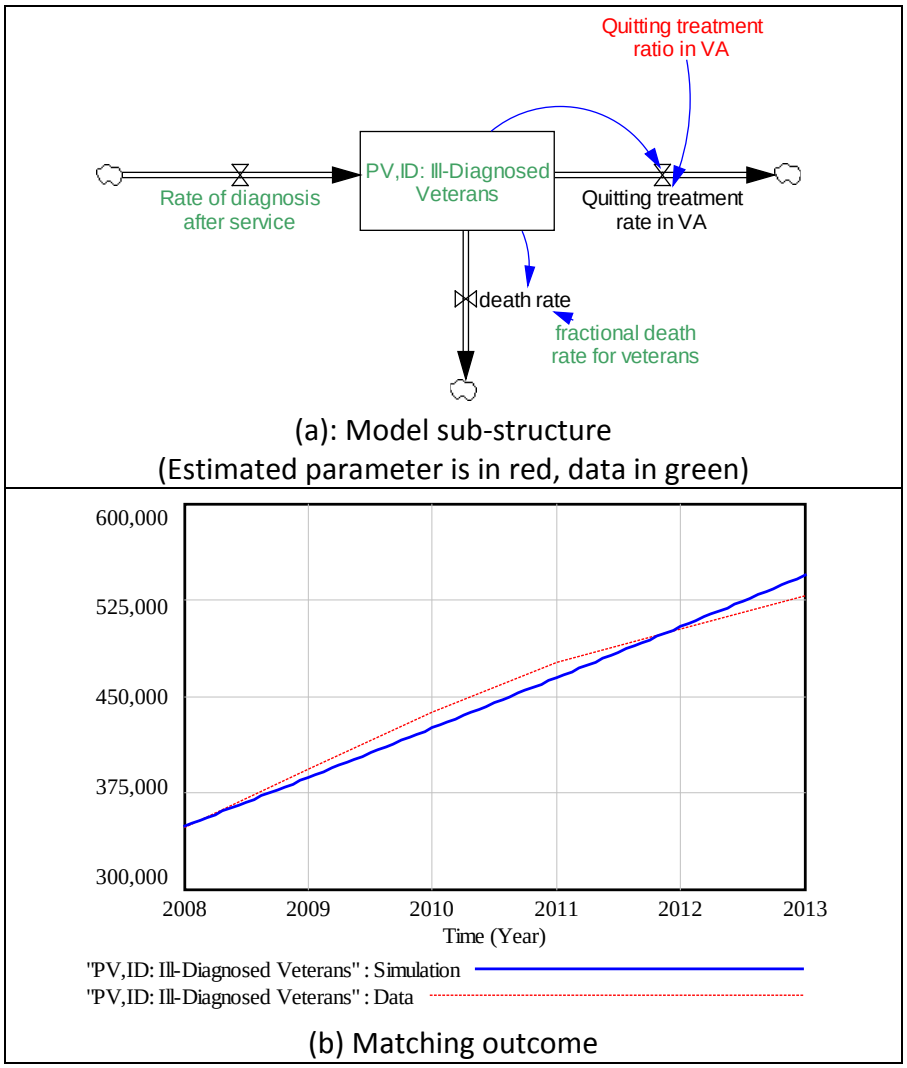


Figure A8: Calibration procedure 2 including model sub-structure (a), and the matching outcome (b).

Calibration outcome: *Quitting treatment ratio in VA* = 0.145

Calibration procedure 3:

- Input: *Deployment to Combat Zone* (
- Table A1, items 2 and 3), *Chance of developing PTSD given combat zone trauma*, *trauma rate per year per person in combat zone* (Table A2, items 2 and 3), death ratio of PM,IU (assumed equal to *fractional death rate for military personnel*; Table A2, item 9), and *Separation of ill undiagnosed service members* (Table A2, item 1.1). Initial PMIU OEF & OIF is zero since simulation starts before these wars. PMH is calculated endogenously using recruitment rate and the military population (

- Table A1, items 4 and 1).
- Payoff function: maximize the fit between the data and simulation of Diagnosis rate of military personnel served in OIF and OEF.
- Outcomes: the only unknown parameter, *Ratio revealing symptoms in military* (Table A3, item 3)
- DOF: 1

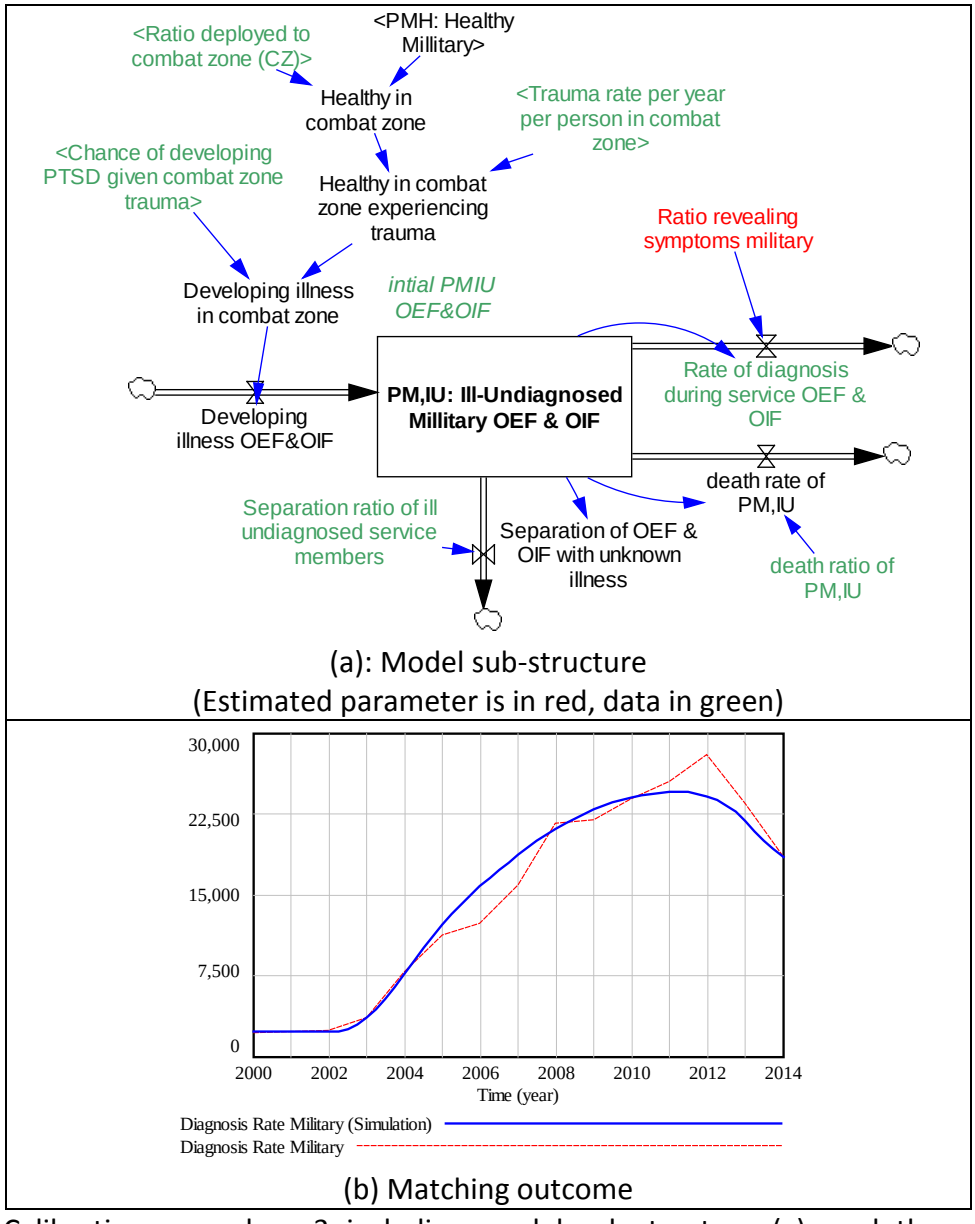
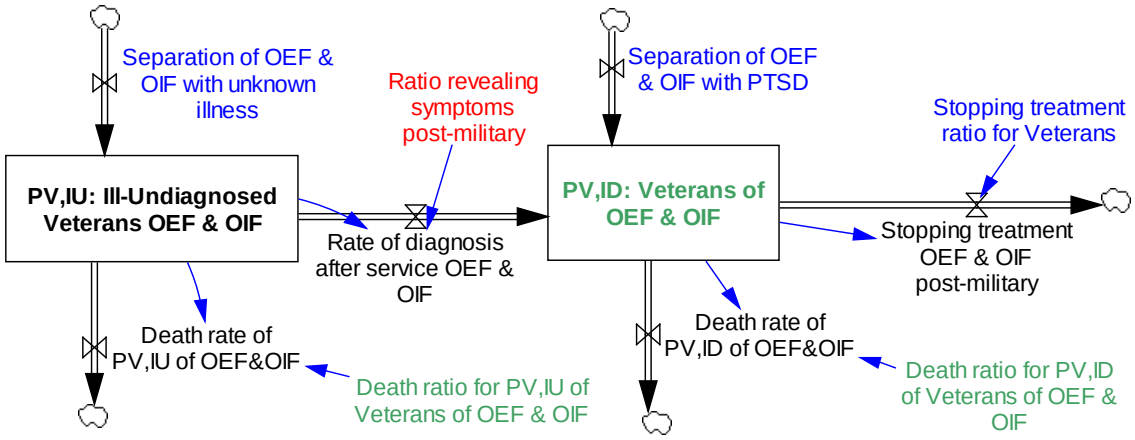


Figure A9: Calibration procedure 3 including model sub-structure (a), and the matching outcome (b).

Calibration outcome: *Ratio revealing symptoms in military* = 0.043

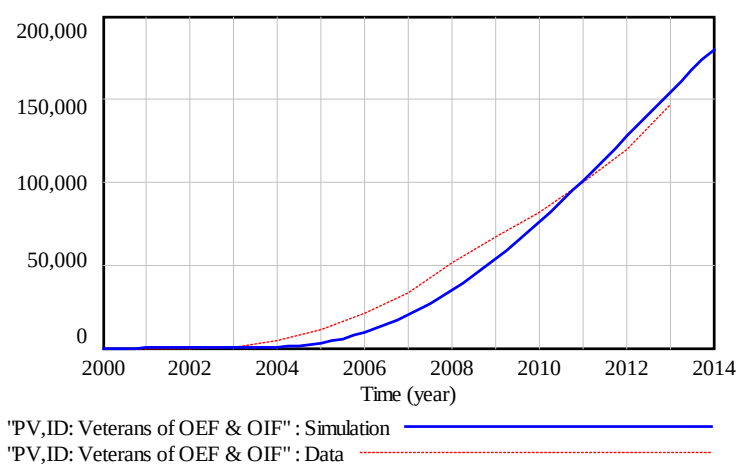
Calibration procedure 4:

- Input: *Death ratios for PV,IU and PV,ID of Veterans of OEF and OIF* (assumed to be equal to *Fractional death rate for veterans*; Table A2, item 8). In addition, Separation of ODF and OIF are calculated from the previous calibrated sub-structures (calibration procedure 3 and calibration procedure 1). Stopping treatment for veterans is the outcome of calibration procedure 2.
- Payoff function: maximize the fit between the data and simulation of OEF and OIF veterans diagnosed with PTSD.
- Outcomes: The only unknown parameter, *Ratio revealing symptoms* for Iraq/Afghanistan veterans (Table A3, item 4).
- DOF: 1



(a): Model sub-structure

(Estimated parameter is in red, data in green, the results of previous calibration procedures in blue)



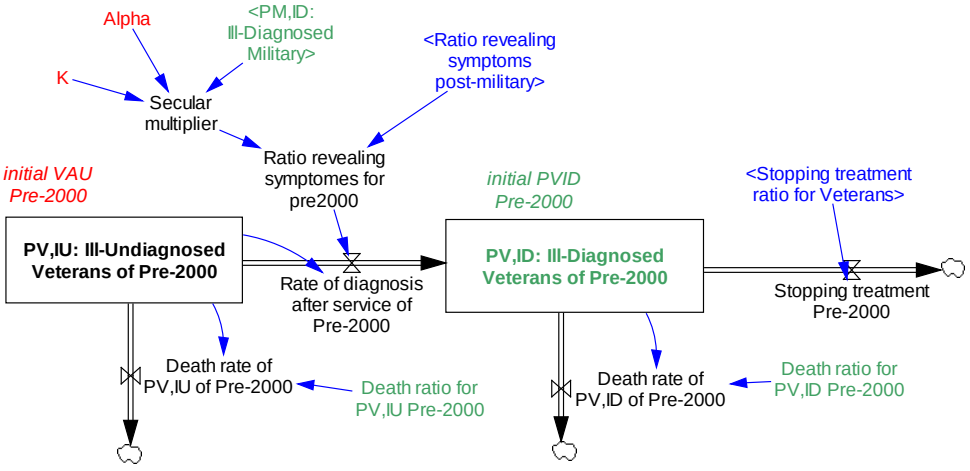
(b) Matching outcome

Figure A10: Calibration procedure 4 including model sub-structure (a), and the matching outcome (b).

Calibration outcome: *Ratio revealing symptoms for Iraq/Afghanistan veterans* = 0.103

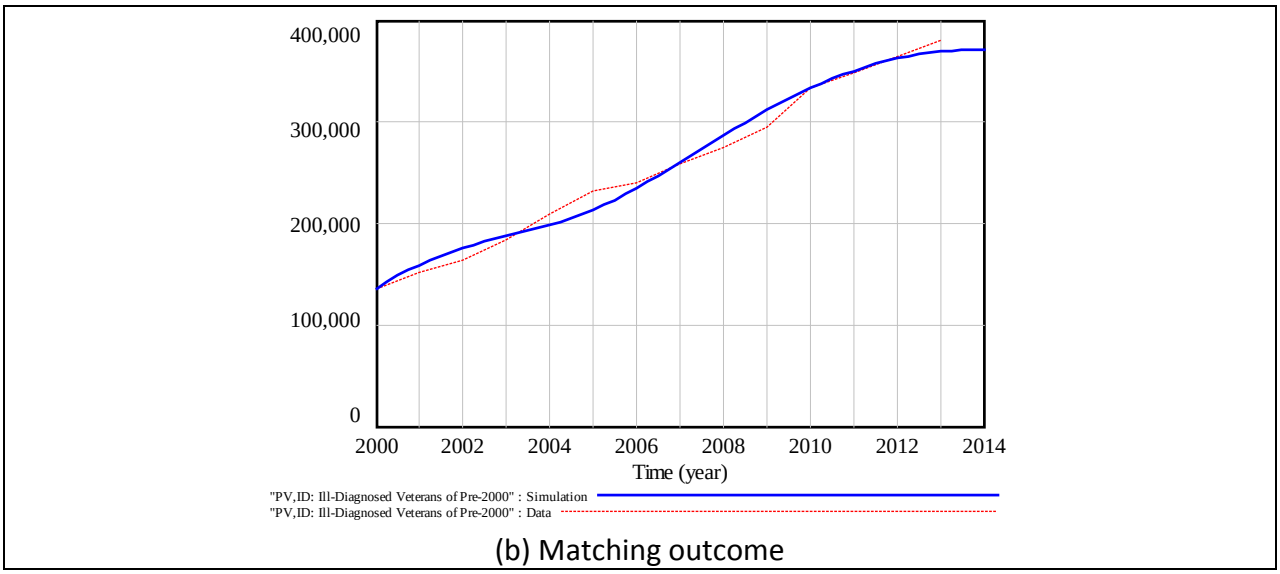
Calibration procedure 5:

- Input: PM,ID (*PTSD diagnosed in military*,
- Table A1, item 7), *Death ratios for PV,IU and PV,ID of Veterans of pre-2000 wars* (assumed to be equal to *Fractional death rate for veterans*; Table A2, item 8), *Initial PVID* (
- Table A1, item 9.2). In addition, *ratio revealing symptoms post military* and *stopping treatment for veterans* is the outcomes of calibration procedures 2 and 4.
- Payoff function: maximize the fit between the data and simulation of PTSD Diagnosed veterans with pre-2000.
- Outcomes: Effects of Iraq/Afghanistan wars on revealing symptom for pre-2000 Veterans.
- Assumption: We first roughly estimated the initial value of VIU to limit potential values for k and α. Based on the population of the Vietnam war veterans and estimated ratios of PTSD, we set the initial value to be equal to 5 million.
- DOF: 1 (after making the assumption for the initial value).
- Note: We later conducted sensitivity analysis on the value of VIU. With 2DOF optimization, Vensim suggest the initial value to be equal to 5.4 million veterans which is very close to our initial assumption. The final results do not change when we change 5 to 5.4 million and even with ± 1 more million shift in this value.



(a): Model sub-structure

(Estimated parameter is in red, data in green, the results of previous calibration procedures in blue)



(b) Matching outcome

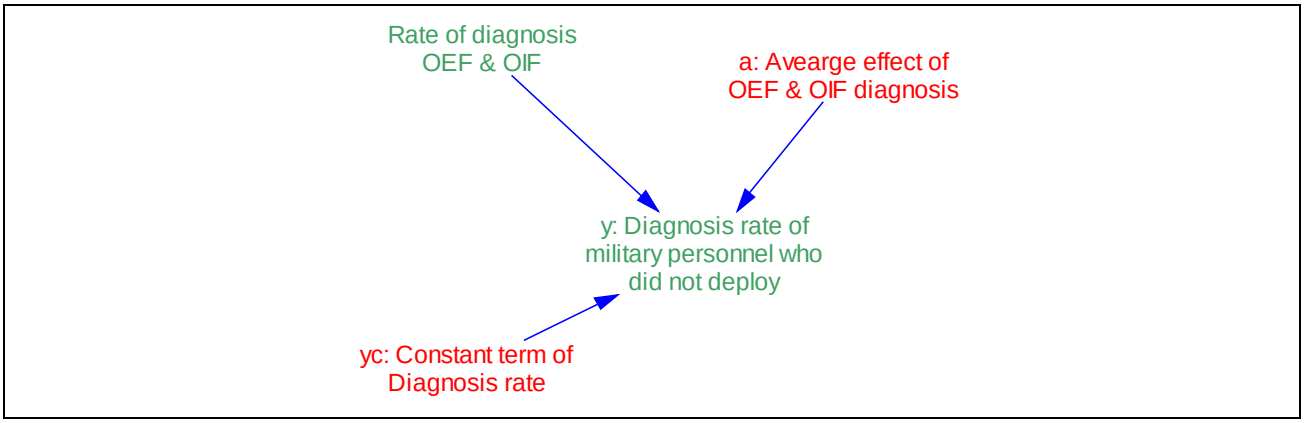
Figure A11: Calibration procedure 5 including model sub-structure (a), and the matching outcome (b).

Calibration outcomes: K= 1.38E-06 and α = 0.4959

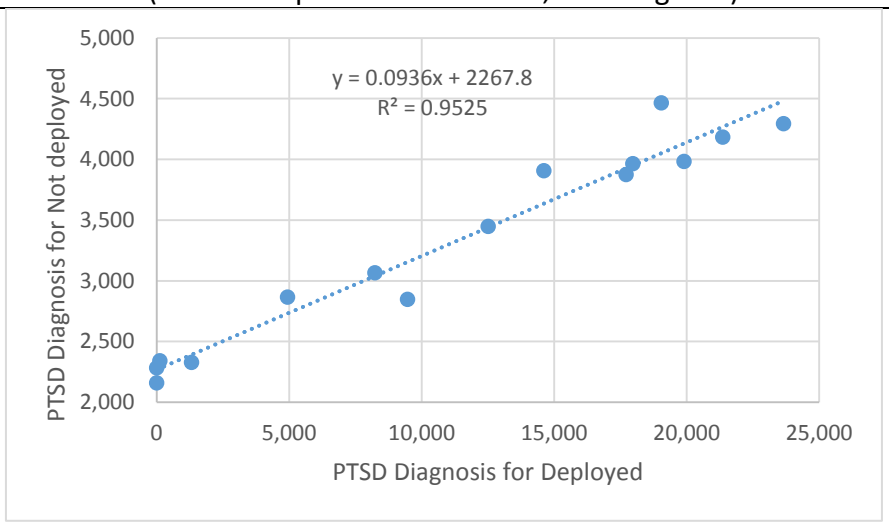
Calibration procedure 6:

- Input: Diagnosis rate of the military personnel deployed to Iraq and Afghanistan (
- Table A1, item 8.1)
- Payoff function: maximize the fit between the data and simulation of Diagnosis rate of the military personnel who did not deploy.
- Outcomes: parameters to estimate diagnosis rate of non-combat related PTSD
- Assumption:

  $y = y_c + a*\text{Rate of diagnosis OEF \& OIF} \quad < P_{M,IU}$
- DOF: 1



(a): Model sub-structure
(Estimated parameter is in red, data in green)



(b) Matching outcome

Figure A12: Calibration procedure 5 including model structure (a), and the matching outcome (b). Note: Calibration outcome: $y_c = 2267.8$ & $a = 0.0936$

APPENDIX 5: Model Validation and Sensitivity Analysis

We report the model's fidelity in replicating the data. Figure A13 shows the model outcomes in comparison with the data for variables: PTSD diagnosed cases in military, PTSD rate of diagnosis in military during service in Iraq or Afghanistan, PTSD rate of diagnosis in Military (non-deployed military personnel), PTSD diagnosed cases in VA, PTSD diagnosed cases in VA (pre-2000), and PTSD diagnosed cases in VA (post-2000 wars, Iraq and Afghanistan).

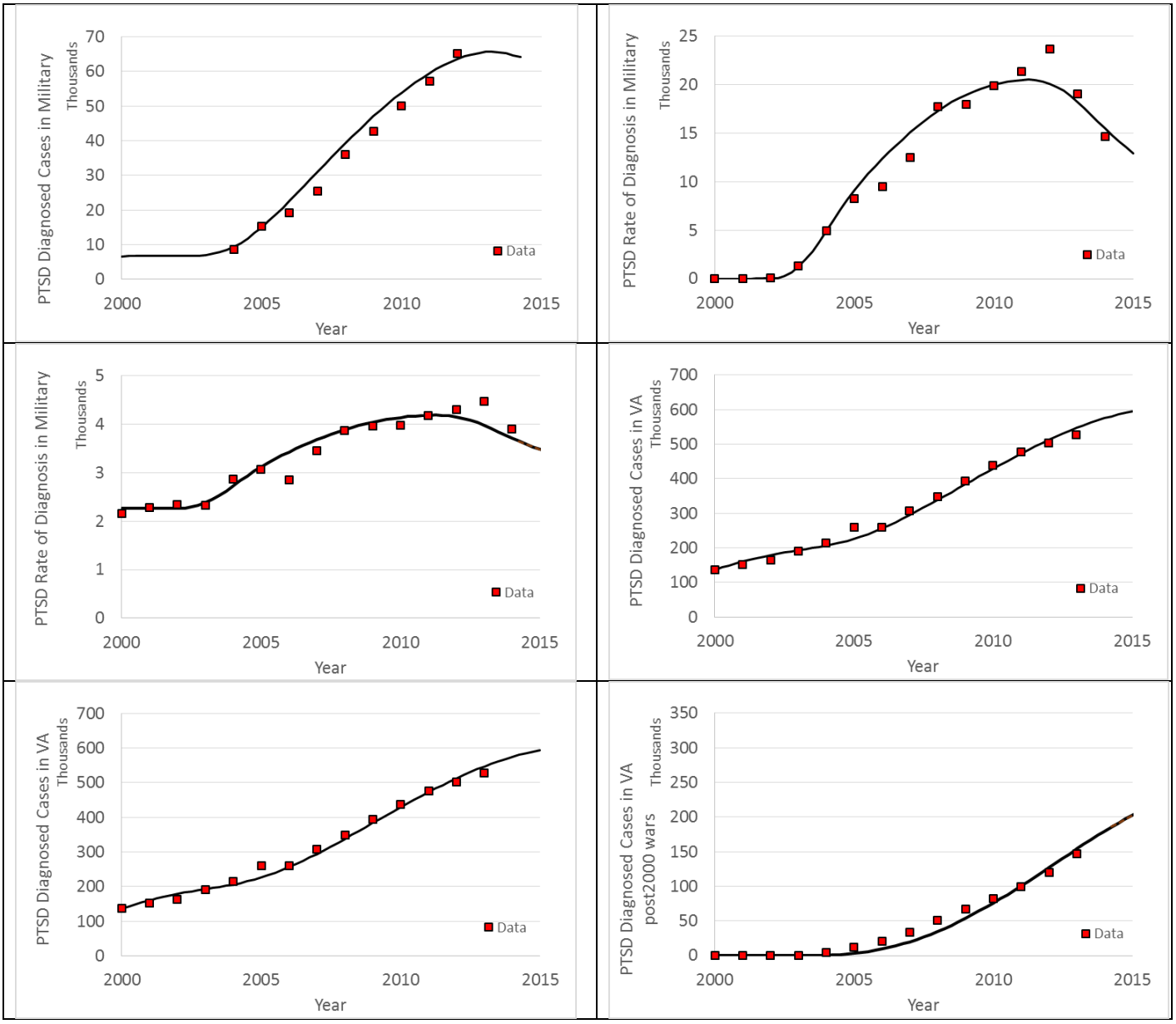


Figure A13: Replication of the data

The model replicated the data with a high correlation. This is not a surprise since our model mainly focuses on the physics of the system, which is the flow of people. What technically validates the model is the simple logical flow in the model—the logic behind the inflows and outflows of the stock variables in the model, see the Vensim model, *PTSD_Simulation.mdl*, in the supplementary files).

We acknowledge the limitations of building complex models like the one we developed. To ensure the reliability of the model's outputs, we conduct sensitivity analysis on the estimated parameters and the ones that we doubt about (given the uncertainty in the data). Here we demonstrate change the value of those parameters (by ±50%) in our second scenario (S2: 2% deployment to intense/combat zones, see Section 3.1 in the article), and examine how the model outputs (PTSD prevalence in military and VA) vary. The results are qualitatively similar for scenarios 1 and 3, or anything between. Results are provided in Table A4. We also include sensitivity results for changing all parameters at a time in the ranges of ±25% and ±50%, reported in Table A5.

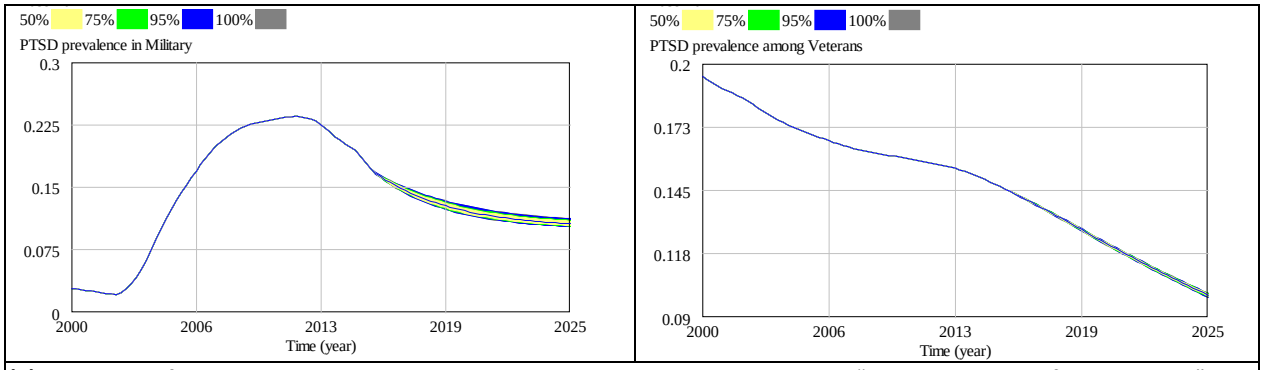
Table A4: Sensitivity analysis results

		Input	**Outputs**		
No.	**Parameter**	**Change in parameter**	**Change in military PTSD Prevalence (Y1)**	**Change in veterans PTSD Prevalence (Y2)**	**Comments** Change in the parameter results in …
1	Separation ratio of ill-diagnosed	±50%	10% - 11%	10% - 10%	±0.5 percent point change in Y1; 0 percent point change in Y2.
2	Average number of traumas a deployed person experiences per year (traumas/year/person)	±50%	7% - 14%	10%-10%	±3.5 percent point change in Y1; 0 percent point change in Y2.
3	Unhealthy recruitment ratio	[0%-5%]*	10% - 13%	10% - 10%	±1.5 percent point change in Y1; 0 percent point change in Y2.

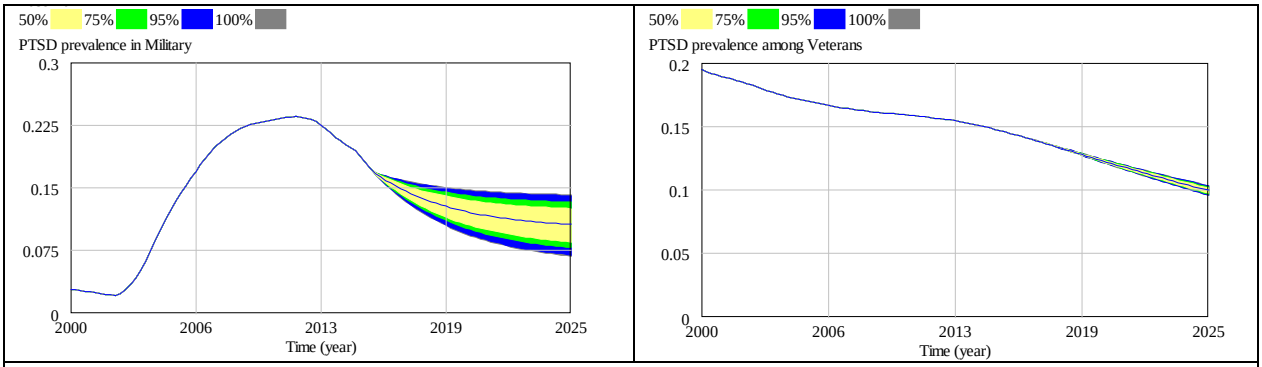
4	Chance of developing PTSD for non-combat related reasons	±50%	10% - 10%	10% - 10%	0 percent point change in Y1; 0 percent point change in Y2.
5	Quitting treatment ratio in military	±50%	10% - 10%	10% - 10%	0 percent point change in Y1; 0 percent point change in Y2.
6	Quitting treatment ratio in VA	±50%	10% - 10%	9% - 11%	0 percent point change in Y1; ±1 percent point change in Y2.
7	Ratio revealing symptoms in military	±50%	10% - 10%	10% - 10%	0 percent point change in Y1; 0 percent point change in Y2.
8	Ratio revealing symptoms for veterans	±50%	10% - 10%	9% - 11%	0 percent point change in Y1; ±1 percent point change in Y2.

* In the base run, the model assumes 1% unhealthy recruitment (people have a history of PTSD). For this parameter, we test a much wider range, due to some speculations about the correct value of this parameter.

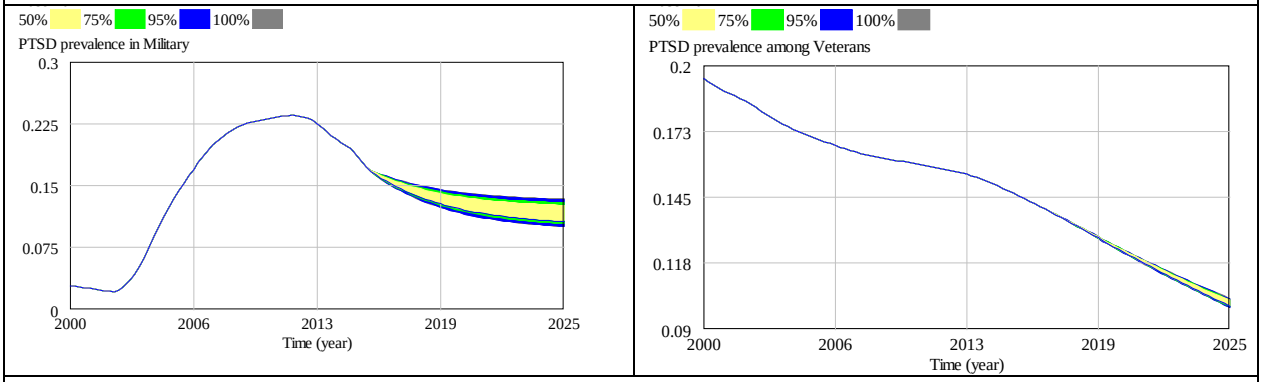
Simulation results are also reported in Figure A14, showing 50%, 75%, 95%, and 100% intervals based on 200 times Monte Carlo simulations.



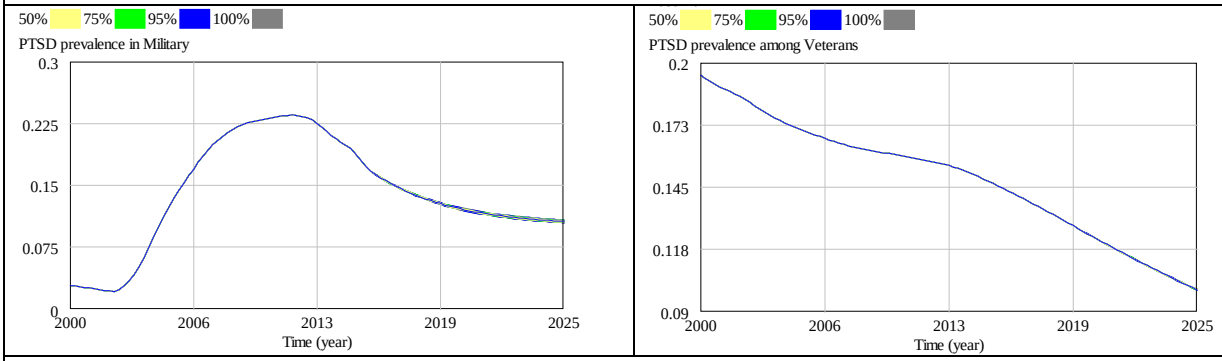
(a) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Separation ratio of ill-diagnosed"



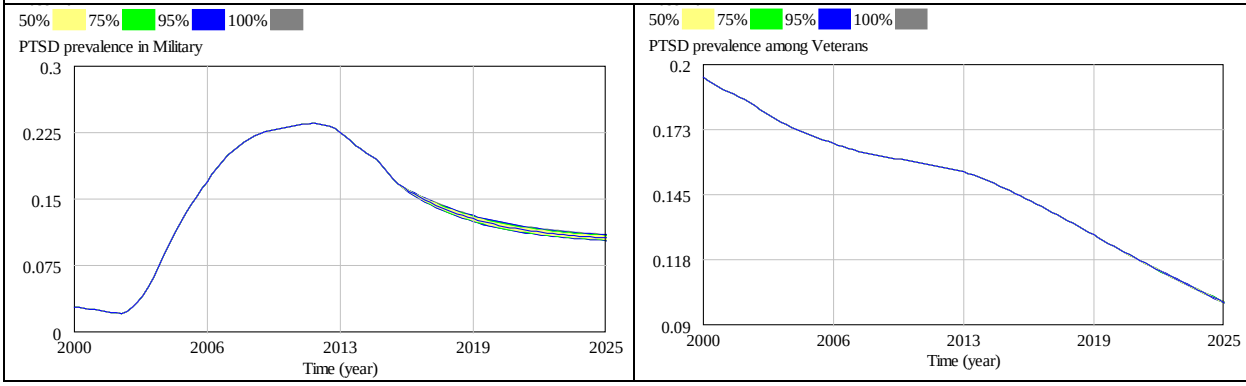
(b) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Average number of traumas a deployed person experiences per year"



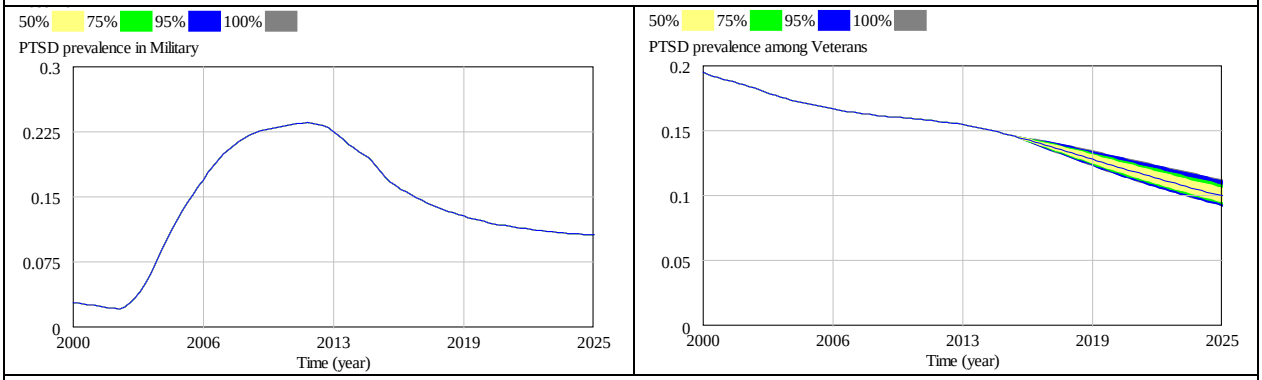
(c) Sensitivity of PTSD prevalence in military and VA to ±500% change in parameter "Unhealthy recruitment ratio"



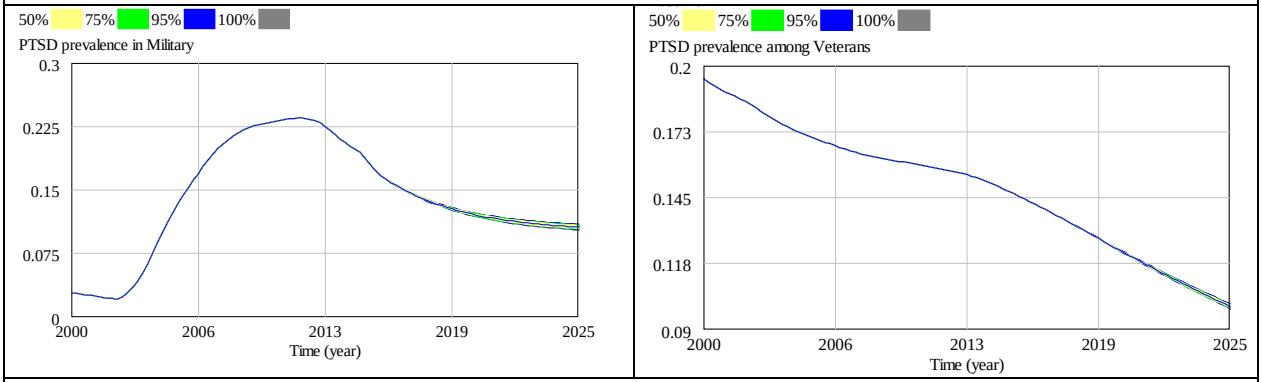
(d) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Chance of developing PTSD for non-combat related reasons"



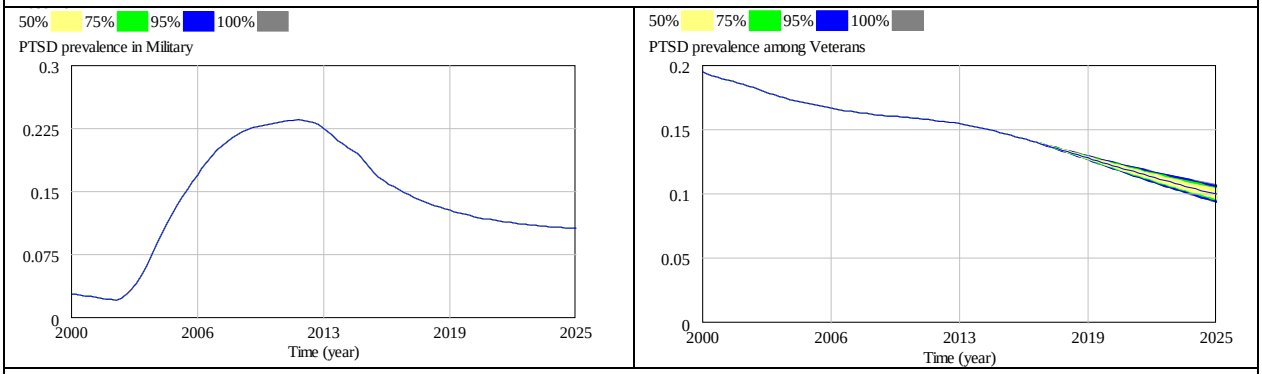
(e) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Quitting treatment ratio in military"



(f) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Quitting treatment ratio in VA"



(g) Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Ratio revealing symptoms in military"



(h). Sensitivity of PTSD prevalence in military and VA to ±50% change in parameter "Ratio revealing symptoms for veterans"

Figure A14: Sensitivity results

In summary, the model outcomes are fairly robust to the changes in all parameters, except 1) Average number of traumas a deployed person experiences per year, and 2) Unhealthy recruitment ratio. For the first parameter, the implication is that if the remaining military personnel in Iraq or other places face with more trauma, e.g., due to escalating situations, there will be more PTSD incidence. This is not a surprise. Our model's prediction is specifically for 2%

deployment in the current situation. And for the second parameter, Unhealthy recruitment ratio, the analysis presents that if less healthy people are hired, we will see a higher PTSD prevalence. This is also not a surprise. Our model runs based on the current status, but we acknowledge that if for any reason less healthy/resilient people are hired in the military in the future, PTSD prevalence will increase. However, we expect potential changes to influence the prevalence in the military by no more than 3 percent point.

Finally, we change all the parameters together to see the effects on the PTSD prevalence. The results are reported in Table A5.

Table A5: Sensitivity results due to changes in all 8 parameters in Table A4

		Inputs	**Outputs**		
No.	**Parameters**	**Change in parameters**	**Change in military PTSD Prevalence (Y1)**	**Change in Veterans PTSD Prevalence (Y2)**	**Comment** Change in the parameter results in…
1	All 8 parameters in Table A4	±25%	9%-14%	9%-11%	±2.5 percent point change in Y1; ±1 percent point change in Y2.
2	All 8 parameters in Table A4	±50%	7%-17%	8%-12%	±5 percent point change in Y1; ±2 percent point change in Y2.

The results present that the estimation of PTSD prevalence among veterans is reliable. However, for the military personnel it can change between 7% and 17% if all important parameters change by 50%. We would like to mention that the most sensitive parameters are the average number of traumas a deployed person experiences per year (traumas/year/person), and the unhealthy recruitment ratio in military. This is not a surprise as if both parameters change (e.g., the situation get more escalated in the middle east and we end up hiring less healthy military personnel), they may influence PTSD prevalence in the military.

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